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ABSTRACT

This volume is the first in a series emanating from the Center for Educational Research and Innovation's project on science, mathematics, and technology education in countries of the Organisation for Economic Cooperation and Development (OECD). It contains eight case studies from the United States presented to an international conference. Four papers on innovations in science education are: "California's Systemic Improvement of Science Education" (Edward Britton); "Chemistry in the Community (ChemCom)" (Martha Lynch and Edward Britton); "Kids Network" (Edward Britton); and "Project 2061" (Martha Lynch and Edward Britton). The four papers on innovations in mathematics education are: "State of California: Restructuring of Mathematics Education" (Norman L. Webb); "The Role of the National Council of Teachers of Mathematics (NCTM) in the Current Reform Movement in School Mathematics in the United States of America" (Thomas A. Romberg and Norman L. Webb); "The Urban Mathematics Collaborative Project: C2ME as a Case Study on Teacher Professionalism" (Thomas A. Romberg and Norman L. Webb); and "Mathematics Accessible Through Technology: The Voyage of the Mimi as an Interdisciplinary and Technologically-Based Program" (Norman L. Webb). An appendix after the NCTM paper contains an overview of the NCTM Curriculum and Evaluation Standards. (MKR)

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OECD DOCUMENTS

SCIENCE AND MATHEMATICS EDUCATION IN THE UNITED STATES: EIGHT INNOVATIONS

PROCEEDINGS OF A CONFERENCE

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PARIS 1993

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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PUBLISHER'S NOTE

The following texts have been left in their original form to permit faster distribution at lower cost.
The views expressed are those of the author(s)

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

— to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
— to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
— to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971) and New Zealand (29th May 1973). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

The Centre for Educational Research and Innovation was created in June 1968 by the Council of the Organisation for Economic Co-operation and Development.

The main objectives of the Centre are as follows:

— *to promote and support the development of research activities in education and undertake such research activities where appropriate;*
— *to promote and support pilot experiments with a view to introducing and testing innovations in the educational system;*
— *to promote the development of co-operation between Member countries in the field of educational research and innovation.*

The Centre functions within the Organisation for Economic Co-operation and Development in accordance with the decisions of the Council of the Organisation, under the authority of the Secretary-General. It is supervised by a Governing Board composed of one national expert in its field of competence from each of the countries participating in its programme of work.

ORGANISATION DE COOPÉRATION ET DE DÉVELOPPEMENT ÉCONOMIQUES

En vertu de l'article 1er de la Convention signée le 14 décembre 1960, à Paris, et entrée en vigueur le 30 septembre 1961, l'Organisation de Coopération et de Développement Economiques (OCDE) a pour objectif de promouvoir des politiques visant :

— à réaliser la plus forte expansion de l'économie et de l'emploi et une progression du niveau de vie dans les pays Membres, tout en maintenant la stabilité financière, et à contribuer ainsi au développement de l'économie mondiale ;
— à contribuer à une saine expansion économique dans les pays Membres, ainsi que les pays non membres, en voie de développement économique ;
— à contribuer à l'expansion du commerce mondial sur une base multilatérale et non discriminatoire conformément aux obligations internationales.

Les pays Membres originaires de l'OCDE sont : l'Allemagne, l'Autriche, la Belgique, le Canada, le Danemark, l'Espagne, les Etats-Unis, la France, la Grèce, l'Irlande, l'Islande, l'Italie, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaume-Uni, la Suède, la Suisse et la Turquie. Les pays suivants sont ultérieurement devenus Membres par adhésion aux dates indiquées ci-après : le Japon (28 avril 1964), la Finlande (28 janvier 1969), l'Australie (7 juin 1971) et la Nouvelle-Zélande (29 mai 1973). La Commission des Communautés européennes participe aux travaux de l'OCDE (article 13 de la Convention de l'OCDE).

Le Centre pour la Recherche et l'Innovation dans l'Enseignement a été créé par le Conseil de l'Organisation de Coopération et de Développement Economiques en juin 1968.

Les principaux objectifs du Centre sont les suivants :

— *encourager et soutenir le développement des activités de recherche se rapportant à l'éducation et entreprendre, le cas échéant, des activités de cette nature ;*
— *encourager et soutenir des expériences pilotes en vue d'introduire des innovations dans l'enseignement et d'en faire l'essai ;*
— *encourager le développement de la coopération entre les pays Membres dans le domaine de la recherche et de l'innovation dans l'enseignement.*

Le Centre exerce son activité au sein de l'Organisation de Coopération et de Développement Economiques conformément aux décisions du Conseil de l'Organisation, sous l'autorité du Secrétaire général et le controle direct d'un Comité directeur composé d'experts nationaux dans le domaine de compétence du Centre, chaque pays participant étant représenté par un expert.

FOREWORD

This volume is the first in a series emanating from CERI's project on Science, Mathematics and Technology Education (SMTE Project) in OECD countries. It presents eight case studies from the United States, four in science, four in mathematics, selected from those prepared for the First Phase of the project and presented to an International Conference on Science, Mathematics and Technology Education organised by the OECD in Paris and held on 5-7 November 1991.

The purpose behind the OECD study is to demonstrate how globally dependent we are becoming on science, mathematics and technology education. Practitioners, researchers and policy-makers are transcending boundaries to search for the best available knowledge to improve the teaching of these subjects and children's learning in the classroom. The eight studies presented here give an indication of the kinds of innovations occurring in the United States. These studies will contribute to a second phase of the CERI SMTE work to be carried out during the period 1993-1995.

Much of this work has been generously supported by the U.S. National Science Foundation and the U.S. Department of Education.

AVANT-PROPOS

Ce volume est le premier d'un projet du CERI sur l'enseignement des sciences, des mathématiques et de la technologie (SMT) dans les pays de l'OCDE, un projet du CERI. Il présente huit études de cas ayant trait aux Etats-Unis, quatre sur l'enseignement des sciences, quatre sur les mathématiques. Ces études ont été préparées dans le cadre de la première phase du projet et soumises à la Conférence internationale sur l'enseignement des sciences, des mathématiques et de la technologie, organisée par l'OCDE et tenue à Paris du 5 au 7 novembre 1991.

L'objectif du projet est de prouver à quel point nous dépendons de ce que nous avons appris en sciences, en mathématiques et en technologie. Les enseignants, les chercheurs et les décideurs s'efforcent de trouver partout où ils le peuvent toutes les infonnations susceptibles d'améliorer l'enseignement de ces matières pour ce que les enfants les assimilent mieux. Les huit études présentées ici illustrent des méthodes novatrices appliquées aux Etats-Unis qui serviront à lancer la deuxième phase du projet SMT du CERI (1993-1995).

Pour ce projet, le CERI a reçu une subvention généreuse de la *U.S. National Science Foundation* et du *U.S. Department of Education.*

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INTRODUCTION

The National Center for Improving Science Education in collaboration with The National Center for Research in Mathematical Sciences Education presents descriptions of eight major innovations in science, mathematics, and technology education in the United States.[1] The descriptions, developed in concert with the Centre for Educational Research and Innovation (CERI), Organisation for Economic Co-Operation and Development (OECD), represent the first phase of an international project involving a majority of the 24 industrialized countries making up the OECD membership.

As the United States and other countries become more globally oriented and interdependent, not only in terms of economic activity, but also in terms of the environment and even day-to-day existence, individual countries are discovering how much they have in common with other nations. In education in particular, policymakers and practitioners are discovering that they need to look beyond their own boundaries to bring the best knowledge available to bear on the improvement of science and mathematics education. OECD believes approaches to reforming education developed in one country may be very helpful to educators elsewhere facing similar issues and problems.

The CERI/OECD case studies project will develop a set of international in-depth studies of innovation in science, mathematics, and technology education, reflecting OECD member nations' growing concerns for more effective education programs in these fields to serve their populations. The OECD countries recognize the need to have an in-depth understanding of the policies, programs, and practices that lead to successful outcomes in science and mathematics education. Further, they desire a greater understanding of how these programs, policies, and practices are implemented in settings where they are successful. What processes support implementation? What roles are played by whom? What outcomes are attained?

Early development of the Science, Mathematics and Technology Education project (SMTE) took place at a meeting organized by OECD/CERI, held in Orlando, Florida, in April 1989. The outcome of this meeting was an issues paper that further refined the concept of the SMTE project for a second meeting of the CERI/OECD held in Paris, March 1990. At this meeting, experts from 18 OECD member countries agreed on the main themes of and approach to the project; guidelines for developing the case studies; and next steps for implementing the project in member countries. Myron Atkin (Stanford University) and Paul Black (London University) co-chaired this group; they continue as the two experts on whom the OECD relies for guidance in this project. Atkin will be involved in the U.S. effort, Black in the case studies in Great Britain.

The group defined the goal of the project as providing models and other information that will help member countries improve curriculum and instruction in science, mathematics, and technology education.

1. **Senta Raizen** and **Edward Britton** are at the National Center for Improving Science Education, a division of The NETWORK, Inc. Raizen directs the Center and Britton is a research associate. Funded by private foundations, the National Science Foundation, the U.S. Department of Education, and the U.S. Department of Energy, the Center's core mission is to promote improvements in science education policies in the United States. It is founded on the principle that improvement of science education must be approached systemically, that is, science curriculum and instruction, the preparation and on-going development and support of science teachers, and the assessment of student learning in science must be addressed in concert.

Thomas Romberg and **Norman Webb** are at the National Center for Research in Mathematical Sciences, a division of the Wisconsin Center for Education Research. Romberg directs the Center and Webb is a senior research scientist. Funded by the Office of Educational Research and Improvement (OERI) in the U.S. Department of Education, the Center has as its mission the provision of a research base for the reform of school mathematics. To accomplish this mission, the Center has created national networks of scholars who collaborate on the identification of reform goals as they develop a long-range research plan designed to improve mathematics in U.S. schools.

It also concluded that the outcome of the SMTE project would be a report based on the case studies of innovations submitted by member countries, concentrating on the processes of change within key areas of concern common to the participating countries. Major agreements reached during the meeting include the following:

- Set in a common framework, the case studies should discuss seven themes:

  -- Context (historical, social, political, educational) within which the innovation was formulated;
  -- Processes by which change was implemented, both as envisioned in planning and as experienced in reality;
  -- Goals and content of the innovation;

  -- Perspectives of the students participating in the innovation;
  -- Methods, materials, equipment, and settings for learning;
  -- Teachers and teacher education; and
  -- Assessment, evaluation, and accountability.

The OECD members believe that these seven themes are important aspects that need to be considered in any innovation. Even if no data exist on one or more of the themes, that absence in and of itself may be significant.

- In terms of the three subjects areas of interest (mathematics, science, and technology), conference participants agreed that they wanted to expand understanding about the following:

  -- Science: redefinition of the scope and structure of science content, including the theme that "less is more," i.e., a better structured and less factually packed curriculum will produce more positive outcomes.
  -- Mathematics: emphasis on a problem-solving approach and application of mathematical knowledge and skills to situations meaningful to learners. A major concern is the extension of mathematics education to more diverse students with subsequently greater demands on teachers.
  -- Technology: ways in which technology is being implemented in the general curriculum of elementary and secondary schools, including motivations for innovations in this relatively new subject area.
  -- Interrelationships among science, mathematics, and technology: ways in which these interrelationships can be woven into the curriculum without impinging on the integrity of the subjects being taught, when each field requires its own structure and sequencing.

An assumption of the case studies project is that the context, characteristics, and implementation features of an important innovation within a given country will turn out to be informative and suggestive for science and mathematics education in other places. Preliminary exploration by several OECD countries of current reform efforts already has demonstrated a number of parallel developments going on in these countries, developments that can be augmented and reinforced in a positive direction through sharing knowledge and experiences. This volume presents the preliminary descriptions developed by the U.S. in preparation for the more intensive case study work to be initiated in fall 1992. The descriptions were prepared by the National Center for Improving Science Education and the National Center for Research in Mathematical Sciences Education, with support from the National Science Foundation and the U.S. Department of Education. The four science and four mathematics innovations described are:

California's Systemic Improvement of Science Education.
California is systemically influencing science instruction by concerted action on four policy fronts: a curriculum framework, an implementation network, statewide testing, and state adoption of instructional materials. The keystone of these, the *Science Framework for California Public Schools* (1990), focuses the content of instruction on major themes in science (e.g. patterns in change, evolution).

Chemistry in the Community (ChemCom).
This course, an alternative to traditional high school chemistry, focuses on sociotechnological problems and serves nontechnical college-bound students as well as students not planning to attend college. ChemCom was developed by the American Chemical Society, partially through support from the National Science Foundation, and is distributed by Kendall/Hunt Publishing Company.

Kids Network.
Telecommunications enable upper-elementary school students across the country and in other countries to exchange scientific data they collect during investigations of real-world problems such as acid rain, waste disposal, and water pollution. Kids Network was developed by Technical Education Research Centers (TERC), principally through support from the National Science Foundation, and is distributed by the National Geographic Society.

Project 2061.
This long-term initiative, led by the American Association of the Advancement of Science (AAAS) and supported by several foundations, endeavors to fundamentally restructure science, mathematics, and technology education. During the first six years, the project has portrayed what should be taught in *Science for All Americans* (1989), and used six geographically-diverse teams of practitioners and others to develop k-12 curriculum models that embody the AAAS recommendations. Over the next several years these teams are translating their models into practice.

State of California: Restructuring of Mathematics Education.
In 1985, the California Department of Education published the *Mathematics Framework for California Public Schools, K-12.* The Framework was used to spearhead the reform of mathematics education in California. Accompanying reform activities included the use of open-ended questions for assessment of math learning; teacher inservice projects coordinated by institutes of higher education; and grants in support of reform.

The National Council of Teachers of Mathematics Standards Project.
In 1986 NCTM organized the Commission on Standards for School Mathematics and in 1989 published *Curriculum and Evaluation Standards for School Mathematics.* In 1991, NCTM published *Professional Standards for Teaching Mathematics.* With these two documents as a guide, NCTM is promoting a systematic program to change the work of students and teachers in mathematics classes and is rallying the support of schools and communities to accept change.

The Urban Mathematics Collaborative Project.
This project is aimed at improving mathematics education in inner-city schools in the United States and to identify new models for meeting the ongoing professional needs of teachers. The UMC project provides the opportunity to study the interaction among business, industry, higher education, school systems, and teachers to create change in the teaching of mathematics.

The Voyage of the Mimi.

The Voyage of the Mimi is a curriculum program that combines videos or videodiscs, computer software, and print materials to present an integrated set of concepts in mathematics, science, social studies, and language arts. The first *Mimi* takes students on a study of whales off the coast of New England. Students apply mathematical ideas of proportional reasoning, triangulation, and navigation to solve problems that arise. In *The Second Voyage of the Mimi*, students go an archeological expedition, using multi-media, in the Yucatan Peninsula of Mexico where they work with the Mayan number system and Mayan calendar, study the relationship between the earth and sun, and deal with compelling social issues.

RÉSUMÉ

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FRANCAIS

RÉSUMÉ

Le *National Center for Improving Science Education*, en collaboration avec le *National Center for Research in Mathematical Sciences*, présente ci-après des descriptions sommaires de huit grands projets novateurs dans le domaine de l'enseignement des sciences, des mathématiques et de la technologie aux Etats-Unis. Ces descriptions, qui ont été rédigées avec le concours du Centre pour la recherche et l'innovation dans l'enseignement (CERI) de l'OCDE, constituent la première étape d'un projet international auquel participent la plupart des 24 pays industralisés Membres de l'OCDE.

A mesure que les Etats-Unis et d'autres pays s'ouvrent davantage sur le monde et deviennent plus interdépendants, non seulement pour ce qui est des activités économiques mais aussi pour ce qui touche à l'environnement et au mode de vie quotidien, ils découvrent qu'ils ont beaucoup en commun avec d'autres pays. Dans le domaine de l'enseignement en particulier, les décideurs et les spécialistes se rendent compte qu'il faut regarder au-delà des frontières pour voir ce qui se fait de mieux dans les autres pays en matière d'enseignement des sciences et des mathématiques afin de s'en inspirer. L'OCDE considère que les réformes de l'enseignement mises au point dans un pays peuvent être très utiles aux enseignants d'autres pays qui sont confrontés au même genre de questions et de problèmes.

Le projet du CERI prévoit la réalisation d'une série d'études de cas approfondies de portée internationale sur les innovations dans le domaine de l'enseignement des sciences, des mathématiques et de la technologie, qui reflètent l'intérêt grandissant porté dans les pays Membres de l'OCDE à l'amélioration et à l'efficacité des programmes d'enseignement dans ces matières en vue de mieux répondre aux besoins de la société. Ces pays savent qu'il faut approfondir la connaissance des politiques, des programmes et des méthodes qui donnent de bons résultats dans le domaine de l'enseignement des sciences et des mathématiques. Ils sont également désireux de mieux comprendre comment ces programmes, ces politiques et ces méthodes sont appliqués dans les environnements où ils donnent de bons résultats ; quels sont les processus de nature à faciliter leur mise en oeuvre ; quels sont les rôles qui reviennent à chacun et quels sont les résultats obtenus.

Le projet sur l'enseignement des sciences, des mathématiques et de la technologie (SMTE) a été défini à une réunion organisée par le CERI à Orlando en Floride au mois d'avril 1989. A la suite de cette réunion, un document thématique précisant mieux la conception du projet a été établi en vue d'une seconde réunion organisée par le CERI à Paris en mars 1990. A cette réunion, des experts de 18 pays Membres de l'OCDE se sont mis d'accord sur les principaux thèmes du projet, sur la méthodologie à suivre, sur la structure des études de cas et sur les différentes étapes de la réalisation de ce projet dans les pays Membres. Myron Aktin (Stanford University) et Paul Black (London University) ont co-présidé le Groupe de direction du projet et le CERI continue de faire appel à leur concours pour la poursuite de celui-ci. Aktin participera aux études de cas sur les Etats-Unis et Black aux études de cas sur le Royaume-Uni.

Le Groupe est convenu que ce projet aurait pour but de fournir des modèles et des informations de nature à aider les pays Membres à améliorer les programmes et les méthodes pédagogiques dans les domaines des sciences, des mathématiques et de la technologie. Le Groupe a également décidé que le projet SMTE devrait aboutir à la rédaction d'un rapport sur la base des études de cas d'innovations pédagogiques soumises par les pays Membres et que ce rapport porterait plus particulièrement sur les processus des réformes pédagogiques dans d'importants domaines d'intérêt commun pour les pays participants. Plusieurs grands points d'accord se sont dégagés lors de cette réunion :

. Les études de cas, qui seront rédigées sur la base d'un cadre d'analyse commun, devraient porter sur les sept aspects suivants :

-- Le contexte (historique, social, politique, éducatif) dans lequel l'innovation a été formulée ;

-- Les modalités de mise en oeuvre de l'innovation, telles qu'elles avaient été prévues au départ et telles qu'elles se sont concrétisées dans les faits ;

-- Les objectifs et le contenu de l'innovation ;

-- Les attentes des étudiants qui participent à l'innovation ;

-- Les méthodes, les manuels, le matériel, et le cadre pour l'apprentissage ;

-- Les enseignants et leur formation ;

-- L'appréciation, l'évaluation et le contrôle.

Les représentants des pays Membres de l'OCDE considèrent qu'il s'agit là d'aspects importants qu'il convient d'étudier dans toute innovation. Même s'il n'existe aucune donnée sur l'un ou l'autre de ces aspects, cette lacune peut être significative.

. En ce qui concerne les trois disciplines retenues (mathématiques, sciences et technologie), les participants à la Conférence sont convenus de la nécessité d'approfondir les points suivants :

-- Sciences : redéfinition de la portée et de la structure du contenu de l'enseignement scientifique, en tenant compte du principe selon lequel "une tête bien faite vaut mieux qu'une tête bien pleine", c'est-à-dire qu'un programme mieux structuré et moins lourd donnera de meilleurs résultats.

-- Mathématiques : il convient de privilégier l'approche fondée sur la résolution des problèmes et l'application des connaissances et des compétences mathématiques à des situations qui présentent un intérêt concret pour les élèves. L'un des grands soucis des participants est que l'apprentissage des mathématiques par des publics plus divers d'élèves risque d'entraîner un surcroît de travail pour les enseignants.

-- Technologie : les moyens d'étudier selon quelles modalités l'enseignement technologique s'intègre dans le programme d'études élémentaires et secondaires ainsi que les raisons qui peuvent pousser à innover dans ce domaine relativement nouveau.

-- Les relations d'interdépendance entre les sciences, les mathématiques et la technologie : comment les intégrer dans les programmes sans compromettre l'intégrité des différentes disciplines lorsque l'enseignement de chacune exige une structure et un ordonnancement qui lui sont propres.

L'une des hypothèses sur laquelle est fondé le projet est la suivante : le contexte, les caractéristiques et les modalités d'application de nouveautés pédagogiques importantes dans un pays donné constitueront une source d'informations et d'idées pour l'enseignement des sciences et des mathématiques dans d'autres lieux. Une première étude menée par plusieurs pays de l'OCDE sur les réformes actuellement mises en oeuvre a déjà permis de mettre en lumière un certain nombre d'évolutions parallèles dans ces pays, évolutions qui pourraient être enrichies et renforcées par la mise en commun de connaissances et d'expériences. On trouvera ici les descriptions préliminaires d'initiatives conçues aux Etats-Unis dans l'attente des études de cas plus détaillées entreprises durant l'automne 1992. Ces descriptions, qui ont été rédigées par *le National Center for Improving Science Education* et le *National Center for Research in Mathematical Sciences*, avec le concours de la *National Science Foundation* et du ministère de l'Éducation des Etats-Unis, portent sur quatre innovations pédagogiques en sciences et quatre en mathématiques :

California's Systemic Improvement of Science Education (p. 19).
La Californie a entrepris un effort systématique d'amélioration de l'enseignement des sciences en menant une action concertée sur quatre plans : élaboration d'un programme d'études type ; constitution d'un réseau d'établissements chargés d'enseigner ces programmes ; réalisation de tests de connaissances à l'échelle de l'état et diffusion dans tout l'état de matériels pédagogiques. Le document de base, intitulé le *Science Framework for California Public Schools* (1990), porte essentiellement sur le contenu de l'enseignement de thèmes scientifiques majeurs (par exemple, les caractéristiques du changement, l'évolution).

Chemistry in the Community (ChemCom) (p. 59).
Ce cours, qui est proposé pour remplacer l'enseignement traditionnel de la chimie au lycée, porte essentiellement sur les problèmes sociotechnologiques et s'adresse aux élèves qui souhaitent suivre des études universitaires non techniques ainsi qu'à ceux qui n'ont pas l'intention d'aller à l'université. *ChemCom*, qui a été élaboré par l'*American Chemical Society*, en partie avec le concours de la *National Science Foundation*, est diffusé par la maison d'édition Kendal/Hunt.

Kids Network (p. 75).
Les réseaux de télécommunications permettent aux élèves du cycle supérieur de l'enseignement primaire des Etats-Unis et d'autres pays d'échanger les données scientifiques qu'ils collectent au cours de leurs recherches sur des problèmes mondiaux d'actualité comme les pluies acides, l'élimination des déchets et la pollution de l'eau. Le réseau d'enfants, qui a été conçu par les Centres de recherche de l'enseignement technique (*Technical Education Research Centers* -- TERC), essentiellement avec le concours de la *National Science Foundation*, est diffusé par la *National Geographic Society*.

Project 2061 (p. 95).
L'*American Association for the Advancement of Science* (AAAS), qui a lancé ce projet à long terme avec le concours de plusieurs fondations, s'est fixé pour but de restructurer radicalement l'enseignement des sciences, des mathématiques et de la technologie. Durant les six premières années, l'AAAS a dressé l'inventaire d'une description des connaissances scientifiques qui devraient être enseignées à tous les Américains, l'a publié dans *Science for All Americans* (1989) et a fait appel à six équipes d'enseignants et de spécialistes provenant de diverses régions des Etats-Unis pour élaborer des modèles de programmes d'études K-12 (du jardin d'enfants à la terminale) conformément à ses recommandations. Au cours des années à venir, ces équipes s'emploieront à donner un contenu concret à ces modèles.

Etat de Californie : Restructuring of Mathematics Education (p. 117).
En 1985, le ministère de l'Éducation de Californie a publié un ouvrage intitulé *Mathematics Framework for California Public Schools, K-12* (Programme-cadre pour l'enseignement des mathématiques dans les établissements d'enseignement public de Californie). Ce programme-cadre a servi à lancer la réforme de l'enseignement des mathématiques dans cet état. Pour accompagner cette réforme, le ministère a aussi préconisé le recours à des questions ouvertes pour l'évaluation des connaissances en mathématiques ; des projets de formation d'enseignants en cours de service

coordonnés par des établissements d'enseignement supérieur et le versement de subventions pour faciliter la mise en oeuvre de la réforme.

The National Council of Teachers of Mathematics Standards Project (p. 143).
En 1986, le NCTM a créé une Commission des normes pour l'enseignement des mathématiques à l'école et a publié en 1986 un ouvrage intitulé *Curriculum and Evaluation Standards for School Mathematics* (Normes pour les programmes scolaires et l'évaluation de l'enseignement des mathématiques). En 1991, le NCTM a publié un autre ouvrage : *Professional Standards for Teaching Mathematics* (Normes professionnelles pour l'enseignement des mathématiques). Dans ces deux documents, qui constituent des guides pour les enseignants, le NCTM propose un programme visant à réformer systématiquement le travail demandé aux élèves et aux enseignants dans les classes de mathématiques et s'emploie à convaincre les établissements scolaires et les collectivités d'adhérer à cette réforme.

The Urban Mathematics Collaborative Project (p. 183).
Ce projet vise à améliorer l'enseignement des mathématiques dans les établissements scolaires des centres-villes aux Etats-Unis et à repérer de nouveaux modèles pour répondre aux besoins concrets des enseignants. Le projet UMC offre à des représentants des entreprises, de l'industrie, de l'enseignement supérieur, des établissements scolaires et des enseignants la possibilité de se rencontrer pour discuter des changements à apporter à l'enseignement des mathématiques.

The Voyage of the Mimi (p. 207).
Le *Voyage of the Mimi* est un module didactique qui associe les cassettes vidéo ou les vidéo disques, les logiciels informatiques et les supports imprimés pour présenter un ensemble intégré de notions mathématiques, scientifiques, sociologiques et linguistiques. C'est ainsi que le premier *Voyage of the Mimi* entraîne les élèves dans une étude des baleines au large des côtes de Nouvelle-Angleterre et les amène à utiliser les notions mathématiques qui sont à la base du calcul proportionnel, des techniques de triangulation et de navigation pour résoudre divers problèmes auxquels ils sont confrontés. Dans *The Second Voyage of the Mimi*, les élèves participent au moyen de différents supports pédagogiques à une expédition archéologique, dans la péninsule mexicaine du Yucatan où, à l'aide du système numérique et du calendrier Maya, ils étudient les révolutions de la terre autour du soleil et se trouvent confrontés à des problèmes sociaux incontournables.

INNOVATIONS
IN
SCIENCE
EDUCATION

17

CALIFORNIA'S SYSTEMIC REFORM OF SCIENCE EDUCATION

Edward Britton

A SKETCH OF THE REFORM

The state of California is trying to improve science instruction through concerted action on four policy fronts:

- a progressive curriculum framework,
- implementation projects,
- revised statewide assessment, and
- state adoption of improved instructional materials.

Through these actions, the state hopes to move the content of science instruction away from coverage of large numbers of basic facts to in-depth treatment of major science concepts. State actions on these fronts are interrelated: "Each aspect of the reform strategy must fit with and reinforce the others so that educators, students, and the public can see and experience the coherence and the power of the undertaking" (Sachse, 1990, p. 1).

The keystone of the systemic reform is <u>Science Framework for California Public Schools</u> (1990). This 213-page document describes what the content of science instruction should be, how it should be taught, and how schools and teachers can implement a good science program. The amount and depth of information in the framework is intended to give readers a clear vision of what school science should become. The framework strongly urges teachers to organize the content of instruction around major themes in science (e.g., patterns of change, systems and interactions, evolution, etc.).

Ideally, classroom teachers who read the framework and embrace its ideals will change their instruction accordingly. However, many California teachers do not have personal copies of the framework. Further, many teachers will need assistance to implement its progressive recommendations. Hence, California[1] is acting on three other policy fronts, described below, to bring about changes in science instruction.

First, three major projects are underway to spur implementation of the framework's recommendations. The implementation projects target individual schools, helping their teachers to reform science instruction. Limited resources prevent California or any other state from delivering staff development directly to each teacher in the state. By reaching enough school faculties to create a critical mass of schools with good science programs, state education leaders hope eventually to transform all California schools. The state's systemic reform strategy currently does not attempt to influence the policies and programs of school districts directly.

The California Science Implementation Network (CSIN) was created to help teachers and administrators, primarily those at the elementary level, to develop school-wide science curricula specifying the science content taught at each grade. The CSIN process helps participants translate the core notions of the framework into specific curricula that are appropriate and feasible at the school level. Summer institutes run by the California Science Project (CSP) mix staff from kindergarten through high school with college faculty who help them share craft knowledge of instruction that embodies the framework's recommendations. The California Scope, Sequence, and Coordination Project (California SS&C Project) helps secondary schools to restructure their science courses to include earth, physical, and life science in every school year.

1 The author uses "California" or "the state" loosely to mean state policy makers for education, particularly staff of the California Department of Education.

Second, the California Assessment Program (CAP) will be adding assessment of science to its testing programs within the next few years, most likely for students in the 5th, 8th, and 10th grade. Further, these assessments will include such innovative exercises as hands-on tasks, essay responses to open-ended questions, and possibly analysis of students' work (portfolios). The CAP already has pilot-tested these approaches to assessment of science learning in thousands of schools. Teachers' experiences with these test have catalyzed many of them to include more activity-based science in their instruction and to participate in CSIN and other staff development opportunities.

Third, California aggressively negotiates with publishers, encouraging them to submit K-8 instructional materials that are consistent with the framework. The hope is that the state's share of the national textbook market will induce publishers to submit such materials. Twenty-five publishers have declared their intention to submit instructional materials for K-8 science during the 1992 adoption process, but the extent to which the materials will reflect the framework's emphases remains to be seen. Fortunately, the National Science Foundation's Triad Program[2] has produced some innovative materials that are consistent with California's Science Framework. In fact, the Triad materials may influence some publishers to substantially revise their conventional materials in order to stay competitive.

Staff of the California Department of Education use Figure 1 to illustrate the relationships between the various initiatives constituting the systemic reform of science education. The foundation of the reform is revising the core curriculum, i.e., identifying what science to teach and how to teach it. This intended curriculum is portrayed in the California Science Framework which draws extensively on Science for All Americans. Soliciting and adopting instructional materials that incorporate the Framework's ideals, developing

[2] The "Triad" curriculum projects were supported by the Education and Human Resources Directorate of NSF; they are discussed briefly in the accompanying OECD paper on Kids Network, one of the Triad projects.

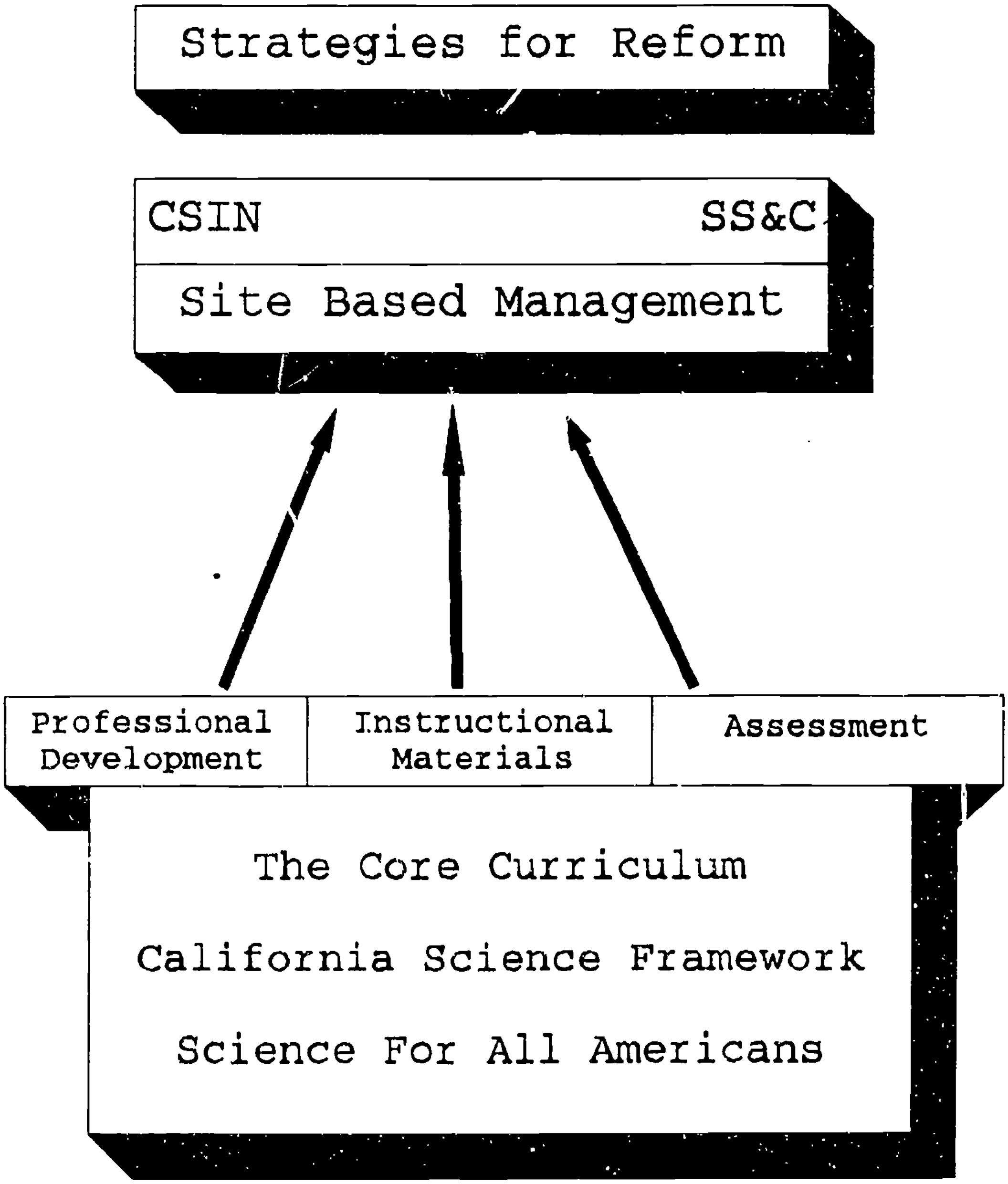

Figure 1. Relationship Between Components of California's Systemic Reform of Science Education.

appropriate state assessments (CAP), and providing staff development opportunities (CSP) are seen as important but insufficient interventions. The two large school-based, teacher-led networks of reform, CSIN and SS&C, are intended as the prime movers for creating an installed base of quality science instruction for all students.

California is beginning to address reform through a fifth policy arena, preservice education, but the efforts are much less extensive than those in other policy arenas. The Commission on Teacher Credentialing (CTC) is revising specifications for science tests for teachers to align with the framework. The California Science Project reaches teachers in part by working with the state's teacher training institutions. Further, faculty on the San Bernadino campus of California State University are spearheading development of a preservice component of the Scope, Sequence, and Coordination Project. The preservice program is intended to help prospective teachers succeed in the kinds of curricular programs being designed in SS&C schools. For example, SS&C teachers will mentor preservice teachers. Also, scientists will collaborate with teachers and science education faculty to improve science teacher preparation. Directors of the San Bernadino program hope to spark similar approaches at each of the 20 California State University campuses that produce 80% of California's teachers.

Context of California's Reform

Improving All Subjects

California's initiatives to improve science instruction are part a broader state effort to improve all subject areas of the curriculum: English-language arts, history-social science, foreign language, science, mathematics, health, and visual-performing arts. In 1983, the legislature and the State Superintendent for Public Instruction established a seven-year cycle for regular curriculum evaluation and revision. During any given year, several subject areas are undergoing revision with each subject at a different stage in a multi-step process.

When state policies for a specific subject area are scheduled for revision, at least four processes are executed over three years. They are (1) revision of the curriculum framework, (2) staff development focusing on the framework, (3) revisions in the California Assessment Program, (4) and adoption of new instructional materials. (The first and last steps are supported by staff of the Office of Curriculum Framework and Textbook Development, part of the State Department of Education.) Thus, the three years between framework approval and adoption of new instructional materials allow time to familiarize the state's teachers and administrators with the desired curriculum before materials change.

The heart of the state's reform across all subject areas is to move instruction away from developing basic skills toward promoting higher-order processes: understanding, problem solving, and thinking. Basic skills development typically results in lists of objectives such as "the student will be able to...." In contrast, California's state curriculum frameworks have a common emphasis on a thinking curriculum. Because the state's frameworks are mutually supportive, teachers are receptive to a new framework coming from the state each year. The emphasis on higher-order processes is illustrated by California's move toward using major themes of science to integrate facts and concepts across scientific disciplines. Much of the thematic approach of the California Science Framework as well as its narrative style and subject matter content were derived from Science for All Americans, a futurist science curriculum framework produced by Project 2061 of the American Association for the Advancement of Science (1989).[3]

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3 Science for All Americans was produced in the first phase of Project 2061, a long-term effort by AAAS to improve science education. It is discussed in another of the four OECD papers reporting on innovations in science education in the U.S.

Freeman (1989, 1990) led a study of curriculum reform in the 50 states and concluded California's reform is state of the art:[4] "California has assumed the lead in the current curriculum reform movement. Its efforts differ both quantitatively and qualitatively from those in the other 49 states" (1990, p. 1). Quantitatively, California is spurring reform aggressively on four policy fronts, more than other states. Only seven states were acting on three or four fronts. (The other states were Hawaii, Indiana, Missouri, New York, North Carolina, and Utah). Qualitatively, the state's conception of higher-order processes clearly is distinct from basic skills. Only 22 percent of the states reported a greater emphasis on higher-order processes than basic skills (Freeman 1989, 1990).

The State's Need for Change

The national climate for education reform has influenced California, but the state's demographic characteristics also are important in understanding why California has initiated vigorous curriculum reform. California has approximately 12 percent of the nation's population but more than 20 percent of the technological work force and desires to maintain its share of this very competitive technical economy. Its minority population has increased dramatically over the past two decades so that now minority students are the majority in the state's 5,500 elementary schools and will soon be the majority in all 12 grades of precollege education. The state's total enrollment is nearly five million students, an very large number that poses a wide range of challenges to the social and educational institutions of the state. The state has no choice other than to acknowledge its diversity and consider the implications of that diversity for all of its policies and programs. In the face of the challenges this state faces, policy makers and educators believe that if

[4] Freeman and a team of five researchers conducted interviews with state curriculum specialists in every state. Curriculum documents were collected from every state and analyzed. A second round of interviews was conducted for the seven most active states.

California can develop effective mechanisms for reform, the experience will benefit not only the state but the nation as well.

A Portrait of the Four Policy Arenas

The Avant-Garde Framework

If avant-garde means using the most advanced and nontraditional ideas, then the Science Framework for California Public Schools is certainly that. It incorporates some leading-edge recommendations of scientists and science education experts. This section of the paper describes the framework in some detail, noting its distinctive elements. The order of topics follows that of the framework's eight chapters, listed in Table 1.

The first part of the California framework, "What is Science?" urges educators to give both the nature of science (Chapter 1) and the major themes of science (Chapter 2) prominent places in the curriculum. The framework advocates that the treatment of the nature of science in the curriculum be elevated from short, discrete, and introductory points (an all too common approach) to concepts that pervade the curriculum. "Teaching What Science Is" includes principles like "Science has its own character as an intellectual activity (e.g., testability, objectivity, consistency)." Such concepts go far beyond the usual approach to teaching "the scientific method," a limited portrayal of the nature of science.[5] In "Scientific Practice and Ethics," the framework encourages explanation of the system in which a scientist operates, a virtually untouched topic in most state frameworks. The "Social Issues" section advocates that teachers embrace controversy on socially sensitive issues (e.g., evolution, conservation, and animal experimentation) by candidly comparing

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[5] Many science textbooks reduce the nature of science to a mere protocol of hypothesis-materials-methods-observations-conclusions, or some version of this sequence.

Table 1

Abridged Table of Contents: Science Framework for California Public Schools

Chapter	No. Pages	Subchapters
		Part I: What is Science?
1. Nature of Science	9	Joy of Science Teaching What Science Is Scientific Practice and Ethics Social Issues
2. Major Themes of Science	11	Why Themes are Essential Some Major Themes of Science Incorporating Themes
		Part II: The Content of Science
3. Physical Sciences	37	Matter Reactions and Interactions Force and Motion Energy: Sources, Transformations, Heat, Electricity and Magnetism, Light, Sound
4. Earth Sciences	36	Astronomy Geology and Natural Resources Oceanography Meteorology
5. Life Sciences	27	Living Things Cells, Genetics, and Evolution Ecosystems

Continued

Table 1 Continued

Chapter	No. Pages	Subchapters
		Part III: Achieving the Desired Science Curriculum
6. Science Processes and the Teaching of Science	28	Scientific Thinking Processes Processes in Context of Child Development Developing Science Concepts Role of Direct Experience in Learning Values and Ethics Science, Technology, and Society School Science: Elementary, Middle, Secondary Teaching All Students
7. Implementing a Strong Science Program	26	Implementation Planning Staff Development Assessment Resources An Implementation Model
8. Instructional Materials Criteria	6	Content Presentation Pedagogy Local Considerations

scientific understanding versus beliefs. In contrast, common approaches play down controversial issues or sidestep them altogether.

Chapter 2 of the framework positions the "Major Themes of Science" as the foundation of the science curriculum as advocated by Science for All Americans, a widely-heralded blueprint for science education (American Association for the Advancement of Science, AAAS, 1989). Themes (also referred to as big ideas, overarching concepts, unifying constructs, and underlying assumptions) are comprehensive ideas that integrate the facts and concepts of different scientific disciplines. The framework urges educators to use themes for organizing science and giving students a conceptual framework for assimilating the rapidly increasing body of scientific knowledge. Using themes in this way contrasts with the status quo of science curricula, that is, covering overwhelming numbers of seemingly isolated facts and concepts. The framework describes six themes: energy, evolution, patterns of change, scale and structure, stability, systems and interactions. It points out that other themes could be used and welcomes this possibility.

The second part of the framework, comprising half of the document, describes what science content should be taught: physical, earth, and life sciences (Chapters 3, 4, and 5, respectively). The presentation of the desired science content is distinctive in two ways: (1) it uses engaging prose rather than statements of goals or objectives; (2) it uses the framework's six major themes of science as the context.The following passage, describing what students in grades 3–6 should know about the characteristics of living things, illustrates the framework's use of prose to portray the desired science content:

> Living things are all composed of cells, or if they are too small to have individual cells (i.e., they are noncellular or one–celled), they still perform all the functions that specialized cells do in a larger body. Living things grow, metabolize food, reproduce, and interact with their environments. All living things have basic requirements of nutrition and growth, needing food, water, and gas exchange for respiration. Plants, as well as some one–celled organisms that can photosynthesize, are able to make food out of air and water, using the energy from sunlight and nutrients from soil or water. All other organisms depend on obtaining food from other sources of energy, usually by feeding on other organisms or biochemical compounds. Living things depend on other living things in many ways. (Energy, Systems and Interactions, Scale and Structure). (pp. 117–118)

All 100 pages of "The Content of Science" part of the framework are comprised of passages written similarly to this one. The Framework's narrative style imitates that of Science for All Americans.

This manner of presenting the desired science content is rare, if not unique. Staff of The National Center for Improving Science Education inspected over 30 other state frameworks and did not encounter any that presented desired science content similarly to California's framework. State frameworks commonly present content as numerous goal statements, as illustrated by the following grade 8 goals from Florida's framework (Florida Department of Education, 1990:25–26):

> Standard C: The student will know basic life science concepts and facts.
> Basic Skill 53: List requirements necessary for life.
> Basic Skill 69: Describe the basic process of photosynthesis.

These Florida goals are the ones that most closely parallel the science content covered in the previous passage from California's framework.[6]

The California framework cites relevant major themes of science at the end of every passage. As the sample passage illustrates, the framework does not merely name the six themes but uses them as the context for describing science content. Many state frameworks do not mention major themes of science or describe them. Some state frameworks do pay brief attention to themes, but often the treatment is restricted to declaring the importance of themes and listing some examples.

The student grade levels that the California framework suggests as appropriate for specific topics are often considerably lower than the grade levels recommended by most other state frameworks for the same topics. The earlier examples illustrate this: California placed the characteristics of living things at the grades 3–6 level while Florida placed similar aspects of this topic at grade 8. Illustrating the point further, the California framework introduces the topics of atoms and chemical changes in grades 3–6, topics that many state frameworks place at higher grades.

6 While there were no goal statements about cells that paralleled the cell concepts in the California example, the Florida framework does begin other aspects of the topic of cells in grade 8.

The framework's treatment of evolution warrants special mention: this topic is prominent in the framework. Being one of the six themes described in Chapter 2, it is often and explicitly used to explain science content in Chapters 3, 4, and 5. Further, Chapter 1 discusses evolution as an example of socially sensitive issues that should be included in classroom instruction. Few, if any, other frameworks give such attention to evolution, even though it is a major theme in science.

The third part of the framework (Table 1 Continued), "Achieving the Desired Science Curriculum," discusses science processes and how to teach science (Chapter 6), how to implement a school science program (Chapter 7), and presents criteria for instructional materials (Chapter 8).[7]

The first two sections of Chapter 6 describe eight scientific thinking processes: observing, communicating, comparing, ordering, categorizing, relating, inferring, and applying. The framework encourages teachers to introduce each process when students are developmentally ready for it (e.g., elementary students can observe but likely would have difficulty with inferring).

The next four sections of Chapter 6 include major recommendations of science education experts regarding instructional practices. The sections describe the following teaching principles: determining students' prior conceptions of science and capitalizing on them; facilitating effective small-group work; promoting scientific values in the classroom; and offering student-controlled, hands-on experiences that are relevant to their lives.

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[7] These criteria in Chapter 8 are part of the fourth policy front in California's systemic reform. They are discussed later in this section of the paper under "**Negotiating for New Instructional Materials**".

These same four sections also recommend some topics for the curriculum: how the enterprise of science operates in the United States and elsewhere; the array of job prospects in science and technology; and how the products of science and technology change society (often referred to as science-technology-society, STS). Comparing this brief treatment of STS in Chapter 6 to the extensive discussions about science content in Chapters 3-5, one concludes that the California framework focuses primarily on core science knowledge from the scientific disciplines, a traditional view of what body of knowledge should constitute the science curriculum.[8]

The next part of Chapter 6 on school science (elementary, middle, and secondary) briefly describes a half-dozen or so instructional strategies that are particularly relevant to these grade ranges. The high school section points out a variety of possible sequences for science courses and explains one possible model called the Scope, Sequence, and Coordination Project (SS&C Project).[9] The last section of Chapter 6 mandates teaching science to historically underrepresented students and to students with limited English proficiency and offers several strategies for accomplishing these goals.

Chapter 7 gives practical tips for implementing an improved science program. "Staff Development" provides guidelines for effective workshops. "Assessment" suggests how administrators can determine the needs of both individual teachers and the school's science program. "Resources" encourages readers to consider the potential of new technologies for science instruction. The final and largest section of Chapter 7, "An Implementation

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[8] Some passages in Chapters 3-5 include discussion of STS topics; however, the crux of Chapters 3-5 is core science knowledge in the scientific disciplines.

[9] The California SS&C Project is described in "**Supporting Implementation.**"

Model," briefly introduces the core ideas in the California Science Implementation Network (CSIN).[10]

Framework Development and Dissemination

The process for developing the framework took more than a year and involved hundreds of people. A state committee of educators, academicians, and representatives from business and industry was established. Meeting over several months, this group divided into sub-committees to draft sections that the entire committee reviewed; some sections were written by consultants. National and international experts gave input on appropriate science content for the new framework. Sachse (1990:2) described the charge given to all the framework's authors:

> To serve as useful guides, curriculum standards must be powerful statements, with a clarity and specificity that surpasses the traditional kinds of educational goals. To ask only for "literacy", or to rely primarily on extensive lists of narrow skills, is to wind up reinforcing the status quo. Thus, developers consistently have been asked to present a point of view on knowledge and learning that discriminates the desired curriculum from the nationally pervasive, low intensity, low expectations curriculum.

The draft of the document as well as an evaluation form were sent to a large number of individuals, including 1500 members of the California Science Teachers Association. Three hundred teachers responded, and 30 teachers and other professionals commented on the framework at a public session of the Curriculum Commission. The framework committee then revised the document, which was approved by the State Board of Education in 1989 and published in 1990.

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[10] CSIN is part of the second policy front in California's systemic reform. It is discussed later in this section of the paper under "**Supporting Implementation**".

Many California teachers probably do not have a personal copy of the framework. The extent to which the framework is distributed depends largely on the actions of individual districts since the California Department of Education supplies only enough copies for districts to distribute one to each school. Districts must order more copies with their own funds if they wish to provide copies for individual teachers. To build support for new curriculum frameworks, the state holds a conference to discuss them in the year of their release. In 1990, each of 10 state regions sent fifteen to thirty administrators, district science specialists, and lead teachers to the awareness conference for the Science framework. Unfortunately, the Department does not collect data on how well the framework is distributed through districts' efforts. While California does not distribute copies of the framework to every teacher, the state does provides copies to teachers as they participate in staff development experiences that support implementation of the framework's recommendations.

Supporting Implementation

California has three major state-sponsored efforts for supporting implementation of the kinds of science instruction recommended in the framework:

- California Science Implementation Network (CSIN) for elementary teachers[11]
- California Scope, Sequence, and Coordination (SS&C) Project for middle and secondary teachers, and
- California Science Project (CSP) for teachers of grades K-college.

The state's goal for the first two programs is to reach 40% of California's science teachers; to date, these programs have served approximately 10% of the teachers. The CSP staff development effort is an important, more recent initiative, but it will not be as massive an endeavor as the two teacher-led programs.

[11] A previous program, the Science Curriculum Implementation Center, was reformulated in 1987 to become CSIN.

The state also has a program, the California Leadership Academy, that helps all new administrators and some existing administrators to be instructional leaders. A new module, consistent with the Science Framework, has been created recently to help principals support quality school science programs.

California Science Implementation Network. CSIN's staff developers help school faculty to specify and develop local K–6 science curricula consistent with the framework's goals. Participating teachers are trained to use two matrices for this purpose. The program elements matrix (Figure 2) helps teachers identify the status of their science program's components (elements) and goals for these components, attainable in three years. Teachers use the content matrix (Figure 3) to develop a K–6 scope and sequence of instructional units for their school. The CSIN staff developers encourage the teachers to specify units that are consistent with the framework, and the matrix itself has a column

Element Goal	Starting Point	Transition	Attainable
Time			
Content			
Instructional strategies			
Integration			
Materials			
Resources			
Assemblies			
Science fairs			
Family science			

Figure 2. The CSIN Program Elements Matrix

<table>
<tr><th rowspan="4">Grade</th><th rowspan="4">Theme(s)</th><th>Physical Science</th><th>Earth Science</th><th>Life Science</th><th colspan="2">Local options</th></tr>
<tr><th colspan="5">Unifying concepts</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th colspan="5">Grade-level concepts and subconcepts</th></tr>
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Figure 3. Content Matrix for CSIN.

that suggests that the major themes of science should be the scaffolding for the units' scope and sequence.

The content matrix can seem intimidating to teachers at first glance, but CSIN staff developers report that teachers' anxiety dissipates considerably once they participate in the process of completing the matrix. Teachers brainstorm about the most important things a student should know and try to identify both existing and new activities that will teach these concepts. The CSIN director has observed that working with this matrix is an educational activity for teachers: they begin to realize what they do and do not know about science.

Approximately 100 classroom teachers have been trained through summer institutes to be CSIN staff developers. Each developer helps five lead teachers (one each from five other schools) to use the matrices; a total of 900 schools have been helped so far. During the school year, staff developers visit or contact each lead teacher three to five times to provide whatever assistance is needed, ranging from workshops on hands-on science to working with school faculty to complete the CSIN matrices. Staff developers maintain a full teaching load so their CSIN activities are extra work. The CSIN director would like to see developers provided with support for 50 percent of their regular time. Although staff developers assist lead teachers throughout the year, the latter are the more influential agents for moving school faculty toward different science instruction since its the teachers who have day to day contact with their colleagues.

Project Storyline, a program within CSIN, is preparing curricula that staff developers will be able to offer as models for implementing an articulated K-6 science program. Storyline emphasizes themes and encourages teachers to envision a curriculum in which students would see connections from grade to grade. The project is not creating materials from scratch but is drawing upon existing innovative materials whenever possible.

The amount of participation in CSIN varies widely: all schools participate in a few districts, some schools participate in other districts, and in still other districts, virtually no schools participate. (This is the case for one of California's large urban districts.) Current funding severely limits the amount of impact data that CSIN staff (consisting of a full-time director and an assistant) are able to collect. CSIN has noted, however, that 95 percent of participating schools return a completed program elements matrix, and 60 percent of the schools return a completed content matrix. Beyond this, CSIN staff has only anecdotal knowledge of how science instruction is changing in participating schools. In some cases, the changes appear to be marked while in others they have been minimal. The CSIN director reports that the Far West Laboratory has done some field work to evaluate CSIN's impact, but results are unavailable as yet.

California Science Project. The California Science Project (CSP) sponsors regional staff development intended to help teachers deliver science instruction consistent with key tenets of the California Science Framework: instruction should be hands-on, i.e., students should work with materials; major areas of science (life, earth, physical) should be approached with a thematic rather than a disciplinary orientation; instruction should enable the successful participation of all students, i.e., including both sexes and all races, ethnicities, and languages; assessment should move beyond limited multiple-choice items to such strategies as performance tasks and portfolios. Although the CSP mission is to serve ultimately the entire grades K-14 community, it has emphasized elementary and middle school teachers during its first years, 1987 to present.

The CSP, established and funded by the state legislature similarly to the California Writing Project and the California Mathematics Project, operates as a program within the University of California. During 1987-1989, the executive director and a small staff developed a niche for CSP by researching prominent or innovative science education activities at both the state and national levels. In early 1990, the CSP funded eight of twenty regional sites that submitted proposals for staff development. During subsequent months, however, CSP central staff decided that some regional efforts were unlikely to attain the Project goals. Hence, the CSP asked for new proposals; existing sites were required to reformulate their work, and new sites were solicited. In early 1991, funds were awarded to three new sites, and significantly restructured efforts were continued at six of the eight original sites. Professional development activities vary widely to address local needs, but all programs are designed to address the main goals of CSP. Faculty from campuses of the University of California and California State University lead the CSP efforts. Late in 1991, CSP funded one of seven sites that applied to specialize in environmental education, a persuasive feature of this site's program was a plan to work with elders of Native American tribes.

A working relationship exists between the CSP and the elementary-level California Science Implementation Network (CSIN), the middle- and secondary-level Scope, Sequence, and Coordination Project (SS&C), and the California Assessment Project (CAP). For example, CSP, CSIN, and SS&C encourage participating teachers to become involved in CAP training so they can help other teachers to administer and evaluate performance-based assessments.

The California Scope, Sequence, and Coordination Project. The state's Scope, Sequence, and Coordination Project (SS&C) recommends that biology, chemistry, physics, and earth science should be taught every year as discussed in Chapter 7 of the California Science Framework. The Project's curriculum sequence starts with mostly descriptive topics in grades 7 and 8, adds some quantitative aspects in grades 9 and 10, and adds the most highly quantitative and theoretical aspects of topics in grades 11 and 12. The SS&C approach emulates curriculum models used in Japan, the Soviet Union, and most European nations, but goes beyond them in trying to coordinate instruction across the sciences. The SS&C approach differs markedly from the traditional "layer-cake" curriculum taught in the United States where most students take only one science per year, typically biology in grade 10, chemistry in grade 11, and physics in grade 12.

Approximately 100 California high schools participate in the project, as well as approximately 100 middle schools which send students to the these high schools. The California SS&C schools constitute one of seven national sites that are striving to implement the Scope, Sequence, and Coordination Project. The National Science Teachers Association created the SS&C Project, coordinates the seven national sites, and has published The Content Core, a guide for curriculum designers (National Science Teachers Association, 1992).

During a planning stage for the SS&C Project, funded by the U.S. Department of Education, each participating California school received an average of $8000. These funds enabled the science department chairs and other science faculty from pairs of related high schools and middle schools to plan how to reformulate their separate curricula into a cohesive single curriculum spanning grades 7–12. Teachers met for roughly 50 hours over two years to revise curriculum materials, reschedule science classes, and develop team teaching approaches.

In 1990, the National Science Foundation provided funds for five implementation activities:

- Faculty from participating schools shared ideas during coordination meetings held at the state levei and at 10 regional "hubs;"
- University faculty provide inservice to the regional hubs;
- Some prospective secondary school teachers are placed in SS&C schools during their internship;
- Teachers conduct classroom research to determine what improvements in student learning occur; and
- The California Department of Education works with outside consultants to document the SS&C Project and with Far West Regional Educational Laboratory to evaluate the project.

California coordinates the SS&C Project with other arenas of the state's systemic reform of science education: The California Assessment Project (CAP) has developed performance-type questions that incorporate earth, life, and physical science; criteria for state textbook adoption encourage materials that coordinate the sciences (three publishers have submitted candidates for middle school adoption); and the Commission on Teacher Credentialing has developed eight certification avenues for teaching coordinated science. The California Department of Education has taken additional steps to ensure the implementation of the SS&C project: the California Science Teachers Association works with the Department of Education to disseminate information about the SS&C Project; the University of California has agreed to accept the science credits from SS&C schools when reviewing student applications for admission; and a group of minority SS&C teachers is addressing the special needs of students from groups underrepresented in science.

Research into at least two aspects of the SS&C Project needs to be conducted. Research is needed to understand both implementation failures and successes. Despite all the above efforts to support SS&C schools, a few of them have discontinued their involvement. Second, researchers should investigate the advantages and disadvantages of different degrees of convergence in curricula among the SS&C schools. The SS&C Project originally promoted local variation, but such influences as university entrance requirements are inducing schools to align their curricula with each other.

Developing Alternative Assessment

The state is changing its statewide assessment program, the California Assessment Program (CAP), in fundamental ways to support the kind of science instruction described in the framework. First, CAP will include science which has not been included in the past. Science assessments will be conducted within the next two years, most likely for students in the 5th, 8th, and 10th grades. Already, a multiple-choice form of assessment of science achievement has been administered in the 8th grade. Honig, State Superintendent for Public Instruction, remarked: "Adding science to the Program has done more to shake up activity in those subjects than anything else we've done" (1989). Partly because the state mandates reporting of CAP scores to the public, CAP influences teachers' instruction. Many of California's elementary teachers formerly spent as little as 20 minutes per week on science; now, many are increasing their instructional time for science to approach 200 minutes per week, the current state recommendation. CAP's influence on what is taught likely will grow because the legislature has mandated that within the next few years CAP must report results for individual students.[12]

CAP is influencing teachers not only to include science but also to employ teaching methods consistent with the framework. The science assessment probably will include clusters of multiple-choice items, hands-on tasks, essay responses to open-ended questions, and possibly collections of students' work. One open-ended question might ask students to justify their responses to one of the clusters of multiple-choice items. Performance tasks could be investigations: collecting data, analyzing them, drawing conclusions, and communicating these. Task designers plan to incorporate earth, life, and physical science in each investigation. Multiple-choice items might be administered before and after the performance components to determine what learning occurred during the investigation. These science assessment procedures exemplify the recommendations of science educators. CAP has received an NSF grant to work with preeminent assessment experts (e.g., R. Shavelson, E. Haertel, and L. Burstein) to design the science assessments.

The state received more than one benefit from the extensive field tests of CAP science assessments that have already been conducted: Thousands of teachers tried new science items in 1990–1991, and thousands more will try new items in 1992. The obvious benefit

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[12] Historically, reporting of CAP assessments has been limited to school scores. Only district-sponsored assessments reported student scores, and few district tests included science.

to CAP is feedback on the items, particularly with respect to issues of administering complex assessment exercises on a large scale. However, California's systemic reform effort also has been a beneficiary. Teachers and students became familiar with hands-on science and enjoyed it. Trained to administer and score these innovative assessments, the teachers constitute a pool of educators comfortable with hands-on science and able to share it with colleagues. The California Science Implementation Network has capitalized on this by training many of these teachers to be CSIN staff developers.

Negotiating for Improved Instructional Materials

The reform leaders in California hope that the state's substantial share of the national market will induce publishers to submit instructional materials that embody the framework. Success on this policy front could have a potent and widespread influence on classroom practice. While some teachers may not attend to the framework, nor participate in an implementation workshop, nor be influenced by statewide assessment, a large majority of teachers rely heavily on textbooks. Weiss (1987) found that 90 percent of grades 4-12 teachers and nearly 70 percent of grades K-3 teachers use textbooks as their main resource for science instruction.

California adopts new instructional materials for grades K-8 every seven years, and 70 percent of a schools' textbook funds from the state must be spent on state-adopted materials.[13] Chapter 8 of the California framework, released in 1990, discussed the criteria the state will use to evaluate K-8 instructional materials for science. In 1991, the state's Office of Curriculum Frameworks and Textbook Development released the 1992 evaluation form for science instructional materials: it mirrors the guidance given to publishers earlier through the framework. The form describes what characteristics are

[13] Instructional materials for high school are not required to go through the adoption process.

desirable in the materials and how they will be evaluated. Table 2, an abridged version of the form, presents the twelve criteria that will be used and describes highly-rated submissions.

For each criterion, evaluators of instructional materials will assign 1 to 5 points as follows: excellent (5), acceptable (3), and unacceptable (1). Each criterion score will be multiplied by its weighting (in parentheses in Table 2) resulting in total scores between 100 and 500. The staff of the Office of Curriculum Frameworks and Textbook Development suggest that materials receiving 350 or more points should be considered worthy of recommendation for adoption. There is no quota limiting the number of materials that can be recommended.

The twelve criteria in Table 2, when grouped and considering their weightings, lead one to conclude that materials are more likely to be recommended for adoption if they have the following characteristics:

- Emphasize major themes of science, deemphasize coverage of facts (Criteria 3, 4);
- Emphasize the nature of science, portray it faithfully (Criteria 2, 5, 7, 8);
- Improve the writing in materials[14] (Criteria 2, 6, 7); and
- Emphasize hands-on investigations (Criterion 10).

The third point refers to California's request for substantial changes in the way authors write instructional materials. First, the state asks that writing should engage the reader, that is, writing should be free of vocabulary-driven passages and instead should consist of lively prose which explains concepts in depth.[15] The framework points to the writing in

[14] California hopes to adopt not only textbooks but also other instructional materials, e.g., some that use technology. The criteria related to writing refer to any instances of prose in any type of instructional materials.

[15] Those interested in analyzing the writing style of science textbooks should see Strube (1989) who identified categories of deficiencies in the writing style of physics textbooks.

Table 2

Abridged Evaluation Form for 1992 Adoption of K–8 Science Instructional Materials in California

Criteria (with Weighting)		Description
1.	Topics are consistent with Content chapters in framework. (5%)	Major concepts from chapters 3, 4, and 5 are present. No major concepts omitted or treated superficially. Less important concepts not given more treatment than major concepts. Physical, earth, and life sciences well represented each year.
2.	Content is treated accurately and correctly. (15%)	Content is presented with relationships among concepts made clear. No errors of interpretation and very few errors of fact are present. Robust scientific generalizations are not stated conditionally.
3.	Content organized around themes, not facts. (15%)	Major themes of science are used to frame instructional program. Concepts and ideas are integrated, connections are made explicit. Material in later units refers to material learned in previous units.
4.	Materials emphasize depth of understanding, not breadth of coverage. (10%)	Materials use themes to interweave concepts under study. Encyclopedic coverage of facts avoided. Concepts studied in depth.
5.	Materials explain how scientific knowledge is gained. (5%)	Materials explain how ideas were developed and why they are considered important. Materials explain how supporting evidence is collected and interpreted.

Table 2 Continued

6.	Language is made accessible to students. (5%)	Key concepts and supplemental glossaries provided for limited-English proficient students. Teachers' editions suggest instruction for limited-English proficient students.
7.	Prose is engaging; scientific language respected. (10%)	Text is written in a lively, engaging style that avoids choppy sentences or passive voice. The language of science is respected and used properly. Euphemisms are not used for controversial terms. Conditional language, such as "some scientists believe," is not used. Glossaries do not merely repeat the definition given in the text.
8.	Science explained as open to inquiry and controversy, and non-dogmatic. (5%)	Character of science explained as in Chapter 1, "Nature of Science." Explanation not confined to a unit, but is integrated throughout.
9.	Connections between science and society presented. (5%)	Science, technology, and society are integrated. Science integrated with other disciplines, especially mathematics, language arts, history, and health.
10.	Real experience and problem-solving emphasized. (15%)	Over 50% of materials involve students in hands-on investigations that are integral to the student program. Activities are not merely repetitions of procedures.
11.	Materials recognize cultural diversity and meet needs of all students. (5%)	Full range of program, including activities, are for every students. Variety of teaching methods used, including cooperative groups.
12.	Assessment oriented toward solving problems, not simply recall based. (5%)	Materials include authentic assessment procedures such as essays, performance exercises, and portfolios of work. Tests rarely ask fill-in-the-blank, short answer, or multiple choice questions.

its own Chapters 3–5 as a positive example. Further, the framework recommends abandoning standard readability formulas because they focus only on the surface structure of reading materials. Using these formulas often results in uninteresting, choppy sentences, which dilute explanations of science.[16] Second, the state strongly discourages such vague phrases as "some scientists believe" when authors could just as easily be specific or definitive. Sometimes, such phrases merely are a device to dilute a controversial topic, say, evolution. Third, glossaries should be functional, containing helpful explanations rather than mere repetitions of the same words used in the main part of the instructional material. Fourth, ideas should be connected throughout instructional materials where possible: ideas in one place should be related to corresponding ideas found in other places.

The state works with publishers to encourage development of innovative materials. In 1990, California held a publishers' symposium where prominent national and state science educators spoke on the needs for appropriate materials. In 1991, a Publishers' Colloquium was held to make sure publishers had internalized California's notions of thematic teaching, active learning, and the use of educational technology in teaching science. Another meeting for publishers in 1991 illustrated the connections between California's Science Framework and the science framework for the state of Texas.

Interested publishers will submit instructional materials for consideration in April 1992. Evaluators will inspect materials in a process lasting several months; subsequently, a state curriculum commission and then the State Board of Education will decide what materials to adopt. Historically, virtually all of the evaluators' recommendations are followed. Panels of 15 evaluators each will be asked to produce consensus recommendations on 10 sets of instructional materials. The state has selected evaluators who are quite familiar

[16] Those interested in protocols for analyzing reading levels which get at the cognitive demands placed on students may want to read Vachron and Haney (1991). They are developing a procedure for determining the level of abstraction (LOA) in science reading materials, a method that probes the deeper structure of reading materials.

already with the framework and will provide them with three to four days of training. This will involve briefings and discussions on both the framework and the evaluation form and presentations by state and national experts on trends in science education and corresponding implications for evaluation of instructional materials.

Thus, California has solicited fundamentally different instructional materials through its framework and its consonant form for evaluating submitted materials. The design and plans for execution of the state's adoption process seems to give California the ability to ensure that adopted materials at least partially fulfill the framework's vision. Will publishers rise to the occasion, and how will the state respond? In 1985, California refused to adopt science materials that ignored evolution or overlooked important ethical concerns. In 1986, all of the proposed K–8 series in mathematics were rejected because they failed to address the state's mathematics framework adequately. These rejections led publishers to replace or substantially rewrite about ten percent of the material in the six mathematics series that ultimately were approved. In 1988, the State Board of Education refused to adopt textbook series for language arts that used literature as window dressing while focusing on the development of isolated skills.

This year, 25 companies have identified materials for science instruction they intend to submit. The major publishers, who historically have controlled a substantial part of the market share, would have to reformulate their former products significantly to rate well in 1992. In contrast, there are several innovative curricula listed for submission, including some of the projects sponsored over the last five years by the National Science Foundation's "Triad" program, which may align more readily with California's adoption criteria. In fact, state leaders have used the existence of the Triad curricula to leverage conventional publishers, advising them to fundamentally redesign their products in order to stay competitive.

State leaders estimate that school districts will spend somewhere between $200,000 and $250,000 on newly adopted instructional materials during the 1992–1993 school year. In the last few years, many school administrators have not spent their instructional materials monies due to controversies over some adopted materials. Also, many principals have been sensitized to the need for new science materials by the field trial activities of the California Assessment Project. Thus, administrators are primed to purchase new science materials and have the money to do so.

Two changes are close at hand for California's adoption process: (1) The legislature has mandated adoption of new instructional materials every two years, and (2) the states of California and Texas are working out a collaborative process for adopting instructional materials. Regarding the first change, although publishers will be able to submit new instructional materials for adoption every two years, adopted materials still will be approved for a seven-year period. The intent of this publisher-supported legislation is to increase the numbers of instructional materials that will be available to teachers and to provide more opportunities for the state to encourage curriculum improvement (e.g., publishers will have opportunities to submit additional versions, in languages other than English, of previously-adopted instructional materials).

Regarding the second change, in 1991, both states declared their intention to increase their influence with publishers by devising a joint adoption process. The first planned implementation of this process will be when California adopts science materials again in 1994. This collaborative arrangement may present some difficulties, however, since the Texas curriculum framework is less forward looking than California's. Further, some glaring contradictions exist, for example, the prominence of evolution in California and its scant treatment in Texas. How will the two states accommodate these differences? Predictions about the impact of the states' plans for joint adoption will be possible only when specifics about procedures and execution are clarified.

Barriers to Changing Classroom Instruction

Since the goal of California's systemic reform is to effect **classroom** changes in science instruction, the seminal question is: Can teachers' science instruction meet framework's vision? The probable answer is: Partially, if there is sustained effort to address some barriers.

Just because the state is coherent in its efforts does not by itself motivate or enable teachers to carry out the new approaches. Three possible reasons are: (1) State and district policies may not be giving teachers the same messages; (2) districts do not necessarily provide support to implement their policies; and (3) the kind of instruction envisioned in the framework is outside most teachers' experience.

Alignment of State and District Policies

California is a state that operates through local control. Districts set their own curriculum and instructional practices in response to state guidance. Cantlon, Rushcamp, and Freeman (1990) examined the interplay between state and district guidelines for curriculum reform in California. In their case study of a large urban district and a medium-sized suburban district, they found that both districts adopted textbooks closely aligned with the state's new frameworks and provided inservice activities to help teachers use these new materials. In the medium-sized district, however, the researchers also discovered the following:

> In two other policy arenas – objectives and tests – the state's call to teach for understanding and thinking in mathematics was counterbalanced by the district's specification of essential skills for high school graduation. . . . This mismatch was further reinforced by the decision to list district objectives in two columns: objectives to be achieved by all students and extension activities for students who need an extra challenge. The state framework takes clear exception to the district's assumption that students should master essential skills as a precondition for working on more challenging tasks. (pp. 26–27)

These researchers did not examine the science curriculum specifically since the Science framework had not been released yet at the time of their study. Discrepancies between state and district guidelines for science instruction may not be as marked. Few districts include science in district-wide assessments; therefore, the influence of the science portion of the California Assessment Project may not be diluted as much by conflicting district assessments as in mathematics. Similar kinds of discrepancies for student goals are likely to occur, however, for example, with respect to inculcating basic science facts as contrasted to teaching major science themes and the nature of science.

Fuhrman and Elmore (1990) compared state and district reform policies in California and five other states; they warn analysts not to assume uniformity in state influence over local districts. Not only do districts' responses to state policy vary, but the state also treats districts differently. For example, the California Science Implementation Network is very active in some districts and almost unknown in others, even in some large districts. Fuhrman and Elmore dispel another faulty assumption, namely, that increased reform initiatives at the state-level result in fewer district-level reform initiatives. In many cases, just the opposite is true: policy initiatives of districts grow in response to state initiatives as districts attempt to translate the latter into locally appropriate actions. Some districts try to implement the spirit of the state policy, but other districts use the state activity as a vehicle to advance their own agendas, which may be at cross purposes to the state's. Thus, future studies of California's systemic reform must carefully examine the district-state interface and avoid unwarranted generalizations.

District-Level Support for Reform

Firestone (1989) points out pertinent issues at the district-school interface. Less research has been done on these interactions than research either on district-state linkages or within-school linkages. Existing studies have documented, however, that teachers' use of reforms is facilitated by consistent prompting from the district. Burdened with many solicitations for their attention, teachers generally will not implement a policy unless there is a message from the top that "we are serious about this." Further study of California's systemic reform should look for indicators of the priority that districts place on science reform and how they communicate this to schools.

Research on the district-school interface also has shown that district support for teachers' implementation of a policy is vital. Little (1989) studied staff development activities in 30 of California's 1,000 districts and found that, encouragingly, every one of them had instituted some subject-area inservice activities corresponding to the state's schedule for implementing new curriculum frameworks. A surprising positive finding was that 75 percent of these staff development opportunities required twelve or more hours; less than 10 percent of them were merely single activities of six hours or less. This finding is especially meaningful because Bowyer, Ponzio, and Lundholm (1987) found that 60 percent more teachers intended to implement ideas from inservice programs when these were delivered over a total of eight or more hours.[17]

Research specifically designed to investigate the content and delivery of district-supported staff development for implementation of the state's science framework would help track and influence its impact. As Little's study demonstrates, many California school districts are sponsoring such staff development activities (1989). It seems prudent for the state to identify these activities, describe them, and work with districts to improve them where appropriate. On the other hand, because science supervisors in larger districts often are overwhelmed with bureaucratic responsibilities and smaller districts usually do not have a science supervisor, districts may not have the expertise to conduct the types of staff development needed to reform science instruction. Thus far, this situation has influenced

[17] These findings come from 818 northern California teachers in 19 counties who participated in NSF-sponsored workshops on Piagetian concepts and their classroom implications.

state leaders of systemic reform to bypass school districts and target individual schools. However, initiatives to work with school districts are under consideration.

Firestone's third finding was that teachers' use of a reform is increased when the issues are important to teachers, and they have influence over design of staff development activities. The CSIN's "grassroots" approach is consistent with this principle. Teachers design their own scope and sequence of instructional units that they will use to implement the framework's curriculum.

A Quantum Leap for Teachers

California's systemic reform for science education poses a real dilemma for teachers: "How can they teach (science) they never learned, in ways that they never experienced" (Cohen and Ball, 1990b:347)?[18] Very few teachers have had the opportunity to experience the science curriculum detailed in the Framework. The best way to comprehend scientific investigation, the nature of science, and the major themes of science is to conduct scientific investigations. But the standard approach of the vast majority of college science courses is to use a knowledge-transmission pedagogy to convey large numbers of facts; most accompanying laboratory courses consistent of cookbook exercises. Even science majors graduating with a bachelor's degree seldom have the opportunity to participate in scientific investigation. It is natural for teachers to model the content and pedagogy of their science instruction after the pedestrian science instruction they received in public school and college.

Because teachers are unfamiliar with the kind of science curriculum detailed in the Framework, they will find it difficult to have a complete conception of the intended science curriculum and to translate that into optimal instruction. Summarizing case

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[18] Their original question was about mathematics.

studies of five elementary-level teachers' responses to California's mathematics reform,[19] Cohen and Ball (1990a:249) reported that:

> Teachers did not simply assimilate new texts and curriculum guides. They enacted new instructional policies in terms of their inherited beliefs, knowledge, and practices. Hence when teachers changed in response to the policy, they did so in terms of their pre-existing practice, knowledge, and beliefs. They reframed the policy in terms of what they already knew, believed, and did in classrooms. The result in many classrooms was a remarkable melange of old and new math teaching.

Two of the teachers observed by Cohen and Ball who were more familiar with the mathematics framework felt their instruction was consistent with it even though many of their practices fell short of the mark, and other practices were clearly in conflict with the framework.[20] The mathematics texts used by the teachers were recently adopted materials that were submitted after California's mathematics framework was issued. The teachers liked these texts and assumed they fully embodied the framework but, in fact, these materials only partially met the framework's vision.

The Cohen and Ball findings should alert science educators to the difficulty many teachers may have understanding the intended science curriculum. There are some differences between the contexts for mathematics and science reforms, however. Elementary teachers spend a lot of time on mathematics instruction and receive much training in how to teach it. The mathematics reform must supplant the older conceptions of mathematics and the dated pedagogical practices. In contrast, elementary teachers spend little time on science instruction and receive less training for it than for mathematics instruction. Regarding instructional materials, while many "new" mathematics materials inadequately reflected the

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[19] The entire Fall 1990 issue of Educational Evaluation and Policy Analysis is devoted to reporting and summarizing these case studies.

[20] Even though the findings from these case studies to appraise California's mathematics reform included only five teachers at an early stage of the mathematics reform, they demonstrate the potential of qualitative research to illuminate teachers' responses to curriculum Frameworks.

Mathematics Framework, staff at the Department of Education anticipate a better alignment between the science materials to be adopted in 1992 and the Science Framework. Thus, some causes of the discrepancies between the aims of mathematics reform and mathematics instruction that Cohen and Ball found may have less influence in science.

Nevertheless, similar problems undoubtedly will exist to some degree; classroom research should be conducted to discover what they are. Even secondary teachers, who have more extensive science content knowledge than elementary teachers, have difficulty understanding and conveying the nature of science (Brickhouse, 1991). Teachers who have an adequate understanding of science do not necessarily command teaching practices that improve students' conceptions. Zeidler and Lederman (1989) found that teachers' ordinary language in the presentation of subject matter significantly impacted students' conceptions of the nature of science.

Questions for Future Research

This paper is only an interim description of California's Systemic Reform in Science Education because the National Center for Improving Science Education plans to continue studying this innovation, subject to funding. Future study plans include intensive field work over the next few years. We close this paper with a summary of questions that might be pursued.

1. What is the extent and pattern of distribution of the California Framework among and within the states' schools? How do teachers who have not participated in state-sponsored programs designed to implement the framework perceive its recommendations?

2. What district-sponsored science reform activities are occurring, and do they align with state-sponsored efforts?

3. What do the core CSIN activities look like? What activities and processes do CSIN participants use as they construct the Program Elements Matrix (Figure 2) and the Content Matrix (Figure 3)?

4. Subsequent to training, what impact do CSIN teachers have in their schools? What interactions do they have with their colleagues? What interactions take place between CSIN staff developers and the CSIN teachers?

5. What do CSP activities look like and what is their impact?

6. To what extent do the science instructional materials that are adopted in 1992 align with the framework?

7. How will the CAP tests, expanded to assess individual students, affect the instructional practices of California's elementary teachers? How much additional science will the teachers provide? Will CAP influence the kinds of science experiences the teachers provide?

8. What are some of the models for science curriculum developed by secondary schools participating in SS&C? What are the differences between models requiring dramatic course restructuring and models requiring less extensive changes. How do these changes affect the faculty, students, and administrators?

9. How are the emergent preservice initiatives progressing? What preservice experiences are being developed at San Bernadino? Are other campuses of California State University adopting them? What revisions are being made in criteria for credentialling teachers?

10. What is in the new science module for the California Leadership Academy?

11. What are California's expectations for students as a result of the science reform program, and what are the time horizons for these expectations?

12. What are the effects on the program of changes in economic conditions in California?

References

American Association for the Advancement of Science (1989). Science for all Americans. Washington, DC: Author.

Brickhouse, N. (1991). Teachers' beliefs about the nature of science and their relationship to classroom practice. Journal of Teacher Education, 41, 3, 53–62.

Bowyer, J., Ponzio, R., & Lundholm, G. (1987). Staff development and science teaching: An investigation of selected delivery variables. Journal of Research in Science Teaching, 24, 807–820.

California Department of Education (1990). Science Framework for California Public Schools. Sacramento: Author.

California Science Project, (1991). What is the California Science Project? Available from CSP, Office of the President, University of California, Oakland.

Cantlon, D., Rushcamp, S., & Freeman, D. (1990). The interplay between state and district guidelines for curriculum reform in elementary schools. Center for the Learning and Teaching of Elementary Subjects Series, 13, Michigan State University, East Lansing.

Cohen, D., & Ball, D. (1990a). Relations between policy and practice: A commentary. Educational Evaluation and Policy Analysis, 12, 249–256.

Cohen, D., & Ball, D. (1990b). Policy and practice: An overview. Educational Evaluation and Policy Analysis, 12, 347–355.

Firestone, W. (1989). Using reform: Conceptualizing district initiative. Educational Evaluation and Policy Analysis, 11, 151–164.

Florida Department of Education (1990). Minimum student performance standards for Florida schools. Tallahassee, FL: Author.

Fuhrman, S., & Elmore, R. (1990). Understanding local control in the wake of state education reform. Educational Evaluation and Policy Analysis, 12, 82–95.

Freeman, D. (1989). State guidelines promoting teaching for understanding and thinking in elementary schools: A 50-state survey. Educational Evaluation and Policy Analysis, 11, 417–429.

Freeman, D. (1990). California's curriculum reform guidelines for elementary schools: 1983–1988. Center for the Learning and Teaching of Elementary Subjects, 16, Michigan State University, East Lansing.

Honig, B. (1989, March). Introductory remarks. Beyond the Bubble, An international symposium on authentic assessment sponsored by the California Assessment Program, San Francisco, CA.

Little, J. (1989). District policy choices and teachers' professional development opportunities. Educational Evaluation and Policy Analysis, 11, 165–180.

National Science Teachers Association (1992). The Content Core: A Guide for Curriculum Designers. Washington, DC: Author.

Office of Curriculum Framework and Textbook Development (1991). Science Instructional Materials Evaluation Form. Sacramento: California Department of Education.

Sachse, T. (1990, June). Strategy paper for mathematics and science education. Available from author, California Department of Education.

Strube, P. (1989). The notion of style in physics textbooks. Journal of Research in Science Teaching, 26, 291–300.

Vachon, M., & Haney, R. (1991). A procedure for determining the level of abstraction of science reading material. Journal of Research in Science Teaching, 28, 343–352.

Weiss, I. (1987). Report of the 1985–86 National Survey of Science and Mathematics Education. Research Triangle Park, NC: Research Triangle Institute.

Zeidler, D., & Lederman, N. (1989). The effect of teachers' language on students' conceptions of the nature of science. Journal of Research in Science Teaching, 26, 771–783.

CHEMISTRY IN THE COMMUNITY[1]

Developed by the American Chemical Society

Martha Lynch, Edward Britton

A SKETCH OF CHEMCOM

Chemistry in the Community, known as *ChemCom* and developed by the American Chemical Society (ACS)[2], is a year-long chemistry course designed for the college-bound, nontechnical student and for the bright student not planning to attend college. The following, fictitious story describes what Mr. Benson and his students experienced during their first ChemCom unit.

During the first day of class, Mr. Benson distributes ChemCom textbooks and has the students read the opening section, excerpts below [full article is a page and a half]. (American Chemical Society, 1988,4)

> **Water Emergency in Riverwood: Severe Water Rationing in Effect.** Water engineers and chemists from the County Sanitation Commission and the Environmental Protection Agency (EPA) will search for the cause of a fish kill discovered yesterday.... Mayor Edward Cisko, citing possible health hazards, today announced the shutdown of the Riverwood public water pumping station and cancellation of the "Fall Fish-In" that was to begin Friday.... Councilman Henry McLatchen described the decision as a highly emotional and unnecessary reaction. He cited the great financial loss that town motel and restaurant owners will suffer from the fish-in cancellation as well as the potential loss of future tourism revenue due to adverse publicity.

After spurring the class to speculate on why the fish died and to debate the merits of Riverwood's response, Mr. Benson explains that the article is the storyline tying together the first ChemCom unit: A progression of fictitious newspaper stories about Riverwood's crisis leavens the unit. Students will investigate possible causes of the Riverwood situation, learn the chemistry needed both to understand the issues and to collect data required to discuss them, and make decisions about water quality problems. The first homework assignment, to be continued throughout the unit, is to scour newspapers and magazines for actual stories on water resource issues (water pollution, water supply, water use). The bell rings.

Students' exiting chatter tells Mr. Benson their curiosity is piqued. But he's uneasy, even a little insecure. After all, today's class was a far cry from his standard introduction to the course: a Wow-'em chemical demonstration show and a lecture delineating "chemistry" and "The Scientific Method."

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1. Information for this study was obtained by interviews with Sylvia Ware, director, educational division, ACS; K. Michael Shea; staff associate for *ChemCom*, ACS; Terri Nally, manager, college chemistry department; Lucy T. Pryde, professor, Southwestern College Chula Vista, CA, (chaired *ChemCom* test committee; currently on leave at the Examinations Institute, Oklahoma State University); staff from Kendall/Hunt publishing company; and printed materials.

2. The American Chemical Society is a large organization of professional chemists and chemical educators with national and international membership.

During the next weeks, the territory most familiar and comfortable for Mr. Benson is helping students learn the traditional chemistry concepts and laboratory procedures needed to delve into water resource issues:

Traditional chemistry topics

common metric units
physical properties of water
types of mixtures and solutions and their properties
molecular view of water (atoms, molecules, compounds, bonds, chemical properties)
symbols and formulas
protons, neutrons, electrons, ions
solubility of solids, gases; solution concentration
characteristics of acids, bases; pH
common acids and bases: names, formulas, and uses
common ions and ionic compounds: names, symbols, charges
molecular explanation of dissolving solids, gases

Traditional laboratory procedures

using a graduated cylinder to measure liquids
filtering liquids with filter paper, funnel, and ring stand
qualitative analysis of aqueous ions: Cl^{-}, Ca^{+2}, Fe^{+3}, SO_4^{-2}
graphing data and interpreting graphical data
testing solubility of solutes in polar and nonpolar solvents

But the unit also takes students through a wealth of applied chemistry topics never broached by most traditional chemistry texts. In fact, most of this information is new to Mr. Benson:

Applied chemistry topics

types and amounts of water usage in geographical areas of the United States
the water cycle: natural purification of water
demand and supply of dissolved oxygen
sources and effects of heavy metal contamination: Pb, Hg, Cd
hard water and water softening
municipal water purification
chlorination of water

Laboratory investigations for applied topics

testing the purity of foul water
keeping a detailed diary of home water use
classifying solutions using Tyndall effects
testing ways of softening water

Moreover, some of the learning activities in ChemCom really put Mr. Benson and his students into uncharted waters (no pun intended). There are the typical yet necessary questions and exercises, called ***Your Turn****, which help individual students check their understanding. But other types of activities are rather novel. Many students relish the little puzzlers,* ***ChemQuandaries****. For example, why does it take 450 liters of water to put a single egg on your plate, or 120 liters to produce a 1.3 liter can of juice? In one of the* ***You Decide*** *activities, Mr. Benson has groups of four students pour through the Riverwood articles, separately listing reported facts and questions prompted by them. Subsequently, students advance possible causes for the fish kill and decide whether sufficient information is reported to definitively substantiate or refute each one.*

Mr. Benson often groups students for laboratory procedures, but grouping students effectively for "You Decide" activities is more challenging. To foster energetic, productive group dynamics he must consider students' general abilities, verbal skills, ability to work cooperatively, etc. Further, Mr. Benson is more used to being an authority than a facilitator.

The unit's culminating activity, "Putting It All Together," further exercises students' group activity skills. The activity's topic for this unit is "Fish Kill in Riverwood - Who Pays?" The entire class prepares for and stages a mock meeting of the Riverwood's Town Council. Mr. Benson has groups of students assume the roles of council members, power company officials, scientists, engineers, chamber of commerce officers, and officers of Riverwood's taxpayer association. The ChemCom text suggests numerous specific facts and issues that each group should consider before the meeting. On meeting day, each interest group has two minutes for presentation and one minute for rebuttal. Following the meeting, each group either prepares an editorial letter to Riverwood's newspaper or prepares the group spokesperson for a simulated television interview.

Mr. Benson feels a sense of accomplishment because the students, most of whom wouldn't have taken his regular chemistry class, are enjoying and learning chemistry -- and more. ChemCom's integrated treatment of science, technology, and society isn't just a hook to engage students, which it does. It also teaches concepts worthwhile for every person to know (e.g., the capabilities and limits of science and technology; the interactions between science, technology, and society; the pressing scientific/societal issues facing our communities, the nation, and the world; the possibility of individuals making a difference through their collective actions; etc.). In fact, Mr. Benson is already wondering how he can infuse some of ChemCom's features into his regular chemistry classes.

ChemCom as an Innovation

What makes *ChemCom* an innovation? (1) *ChemCom's* goal is to help students become scientifically-literate citizens rather than only to provide a base of knowledge for studying chemistry in college. (2) Hence, the *ChemCom* curriculum treats scientific, technological, societal topics in an integrated fashion. (3) Further, many *ChemCom* activities require small student groups to make decisions on issues having scientific, technological, and societal factors.

ChemCom designers argue that for students to be scientifically-literate citizens, they must understand technological and scientific aspects of chemistry in concert with traditional science concepts. Such citizens need to understand the nature of the scientific enterprise, and the interactions that exist between science, technology, and society. The following four (out of 32) major *ChemCom* concepts illustrate the above principle (American Chemical Society, 1988, xxix).

- Expert agreement upon underlying scientific and technological facts related to a societal or technological issue does not necessarily imply that experts will agree on a particular "fix." Social, political, economic, and ethical values influence the opinions and advice of experts.

- All technological benefits are associated with some level of risks/costs/burdens.

- Individual actions that may seem insignificant considered alone, can have major societal and ecological impact when multiplied by similar actions of many individuals.

- Our present state of knowledge about any given societal/technological issue is likely to contain imprecision, inaccuracy, and uncertainty. Society must act upon the best available information with the understanding that additional information may call for subsequent reevaluation of an issue and/or previous solution.

ChemCom's goal leads to the other two innovative characteristics listed above. *ChemCom* units use realistic community issues (e.g., Riverwood's fish kill) to interweave scientific, technological, and societal topics. While discipline-based science topics comprise all or most of a traditional chemistry course, *ChemCom* also includes related technological and societal topics.

Although less course time is available for traditional science content, *ChemCom* still addresses most traditional chemistry topics, generally by developing each topic in less depth. *ChemCom's* design principle is that content is introduced on a "need to know" basis, i.e., chemistry concepts are developed to the extent students need them, along with technological and societal concepts, to understand the units' community issues.

Some notable differences exist, however, between the science topics covered in *ChemCom* versus traditional courses. *ChemCom* covers much more biochemistry, organic, and nuclear chemistry than do traditional courses. But it does not teach atomic and molecular orbitals, kinetics, equilibrium, or energy in reactions, and only briefly treats molecular structure.

Finally, decision-making activities are integrated into every unit in *ChemCom*. Through such activities, *ChemCom* authors believe students develop the reasoning skills needed to function in a world driven by science and technology. Also, they believe placing the decision-making exercises in a setting of cooperative learning leads students to "own" the content, not struggle with mastering it: by having to teach and present concepts to each other, they "buy" into their own learning. Examples of student-centered, cooperative learning activities include surveys, interviews, simulations and debates (O'Brien, 1988). The developers stress that the teaching approach for *ChemCom* differs from traditional chemistry courses. In *ChemCom*, teachers are not central to the classroom activities. Rather, they guide students who work in small groups in cooperative learning activities. Table 1 summarizes key differences between traditional chemistry and *ChemCom*.

CONTENTS OF *CHEMCOM*

The Units

ChemCom is delivered in eight units, listed in Table 2. Each is based on societal issues. The developers recommend that the first four units be covered in order as presented in the text. The order and extent to which the remaining units are covered is left to teachers' discretion.

Chemistry Topics

ChemCom covers the science concepts listed in Table 3. Throughout the course, when a concept or exercise builds on previously learned information, the specific reference is given. This reinforces the original lesson and helps teach the new one. Table 3 indicates where the concepts are introduced, and where they are elaborated and applied. The *ChemCom* text includes a glossary.

Table 1

Comparison of Traditional Chemistry with ChemCom (Ware, 1990)

Traditional Chemistry	ChemCom
Preparation	Popularization
Generating knowledge	Applying knowledge
Discipline focus	Societal issue focus
Science on lab bench	Science in the community
Model building	Decision-making
Mastery of content	Ownership of content
Individual problem-solving	Small-group work

Laboratory Activities

The curriculum is about 50 per cent laboratory-based, and laboratories are included in the *ChemCom* text. A typical unit includes five laboratory activities. These are integrated into each lesson to emphasize their relevance to the particular social issue or problem. The laboratory is inquiry-based, meaning that the students are not given the answers, but must find them through analysis and experimentation. According to one *ChemCom* teacher (Berry, 1988), the laboratory setting allows students to learn by doing. It is the appropriate setting to learn the scientific method as well as manipulative skills, data collection and data analysis.

There are no conversion costs for laboratory equipment or supplies. Laboratory supplies for *ChemCom* labs are no more expensive than those used in traditional chemistry labs. They are usually obtained in hardware and grocery stores rather than chemistry supply companies.

The *ChemCom* teachers' manual explains how to microsize laboratory activities, an increasingly common practice in traditional chemistry (Gross, 1989). Microsizing (scaling down in amounts of sample, reagents, and equipment for a protocol) is a common laboratory modification which has a number of benefits: less time needed to perform laboratory exercises, less expensive, smaller amounts of reagents and samples needed, less storage space needed, and less waste generated. To illustrate the size differences, microsized experiments only require spot-plates and eye droppers while traditionally-scaled experiments require test tubes and pipettes.

Table 2

ChemCom Units with Illustrative Sample Topics

ChemCom Unit	Sample Topics
Supplying our Water Needs	water quality, supply, and demand.
Conserving Chemical Resources	properties, sources, and uses of chemical resources.
Petroleum: To Build or Burn?	source, uses, alternatives to petroleum
Understanding Food	food and nutrition, metabolism, world hunger
Nuclear Chemistry in Our World	radioactivity, pros and cons of nuclear power
Chemistry, Air and Climate	properties of gases, threats to the atmosphere
Chemistry and Health	chemistry in human metabolism, threat of drugs
The Chemistry Industry	industrial processes, electrochemistry

Decision-Making Activities

In *ChemCom*, students are exposed to decision-making in three forms (American Chemical Society, 1990):

- **A Chem Quandary**; a short exercise of 10-15 minutes conducted 3-5 times per unit, designed to provoke thought and discussion.

- **You Decide**; similar to a laboratory experiment, but involving no equipment or chemicals. This type of activity is intended as a problem-solving exercise with students working in groups. It takes from 30-50 minutes, and some of the activities involve homework. Approximately five are conducted per unit.

- **Putting it All Together**; a closing exercise after each unit where students sum up, review, and apply the principles learned throughout the unit. Each of these activities is intended to provide a forum to discuss/solve the societal problem introduced in the unit. They usually take two days of class time and are preceded by individual or group research.

In addition to the decision-making exercises, drill and practice exercises, called **Your Turn**, are conducted approximately 9 times per unit. This activity usually involves homework followed by classroom discussion (5-15 minutes). Students work individually. This type of exercise is intended to ensure that students acquire the necessary skills to use the metric system, balance equations, know nomenclature, perform computations, graph, and analyze graphs.

Table 3

Chemical Concepts Grid: ChemCom (Ware, 1990)

	ChemCom Units							
Concept	Water	Resources	Petroleum	Food	Nuclear	Air	Risk	Industry
Metric (SI) measurement	I	U	E	U	U	U	U	U
Scale and order of magnitude	I	U	U	U	U	U	U	U
Physical and chemical	I	E	E	U	E	E	E	E
properties	I	U	E		U	E	U	U
Solids, liquids, and gases	I	E	U	U	U	U	E	U
Solutions and solubility								U
Elements and compounds	I	E	E	E	E	U	U	U
Nomenclature	I	E	E	E	E	U	U	U
Formula and equation writing	I	E	E	E	U	U	U	
Atomic structure	I	E	E		E			U
Chemical bonding	I	U	E	E		U	E	U
Shape of molecules	I		E	U			E	E
Ionization	I	U	E		E	E	E	
Periodicity		I/E/U						U
Mole concept		I	E	U	E	E	U	U
Stoichiometry		I	E	E		U	U	E
Energy relationships		I	E	E	E	E	E	U
Acids, bases, and pH	I			E	E		E	E
Oxidation–reduction		I		U		U	U	U
Reaction rate/kinetics				I	E	U	E	
Gas laws						I/E/U		I/U
Equilibrium								U
Chemical analysis	I	E	E	E		U	U	E
Chemical synthesis			I			U		
Biochemistry				I	U		E	E
Industrial chemistry	I	E	E	E	E	E	E	
Organic chemistry			I	E			E	
Nuclear chemistry					I/E/U			

CODE: I → Introduced
E → Elaborated
U → Used

RESOURCES

The ChemCom Text

The course is taught from one textbook. Supplemental texts or materials are not necessary to teach *ChemCom*. However, the teacher's edition includes extensive references to audio-visual and computer software that might add to a lesson. Field tests have indicated that the reading level of *ChemCom* is at about the 10th grade.

A second edition will be available in 1992 as well as a teacher's edition. The recently revised text reflects feedback from 10 reviewers who were *ChemCom* teachers. The reviewers provided feedback based on their classroom experience with *ChemCom*. They reported on what worked, what did not work, and included student feedback. Also provided was student-generated data for inclusion in the laboratory exercises. An editorial board consisting of university professors, members of industry, and high school teachers made decisions on what revisions would be included in the second edition.

The new edition includes refinements on decision-making approaches and information about careers that reflect the use of chemistry in society, for example, a potter who uses natural dyes for pigments, a conservation scientist, a division chief of sanitation, a director of aquatics who must clean pools in a non-destructive manner. Career opportunities also are featured periodically in the ACS newsletter *Chemunity News*.

The ChemCom Exam

This end-of-the-course examination, consisting of 60 items, is designed to be administered over two class periods and requires 80 minutes to complete. The format includes multiple-response options, linked event-decision style questions, and grid questions, which allow measurement of student achievement that is not easy to assess with single-answer, multiple-choice items. Figure 1 is a sample grid/matrix question. Part 1 of the exam consists of 40 single-answer, multiple-choice questions, organized by unit. Part 2 contains 20 novel test questions, many of which require synthesis of information from more than one unit. Through articles in *Chemunity*, teachers were encouraged to familiarize students with the format by incorporating these less traditional assessment approaches in classroom activities.

Figure 1. Sample Grid/matrix Question

A. C_2H_4	B. C_3H_8	C. Distillation
D. $C_{10}H_{22}$	E. Boiling point	F. $C_{20}H_{38}$
G. Melting point	H. Crackling	I. Hydrocarbons

Q1 Which are likely to be gases at room temperature?
Q2 Which could be used to prepare polymers?
Q3 Which are unsaturated?
Q4 Which techniques are used to separate fractions?
Q5 Which changes when atmospheric pressure changes?

Each question or assessment criterion fits one of three levels: **understanding** (student explains, identifies, or describes the features of and ideas related to information given); **analysis** (student analyzes critically the relationship between information given and the conclusion drawn); **generalization** (student draws over-all conclusions from specific information given).

Software

Computer software has been developed to accompany *ChemCom* through a collaborative project, SCIP (the SERAPHIM/*ChemCom* Interface Project), with Project SERAPHIM, a clearinghouse for instructional computer software and information in chemistry, and the *ChemCom* project. SCIP software is available to supplement several *ChemCom* units and covers such topics as the identification of a pollutant that is killing fish in a lake or pond; wastewater treatment, and the effects of primary, secondary, and tertiary treatment on the pollution level in a river; the maintenance of mineral resources; gasoline; the operations of a refinery; nuclear chemistry; solids, liquids, and gases; the manufacture of sulfuric acid, and a fictitious potential industrial pollutant, BCTC. A catalogue of SERAPHIM software can be obtained free of charge from Project SERAPHIM at the Department of Chemistry, University of Eastern Michigan University. Disks usually contain more than one program and cost approximately five dollars. The *Teachers Guide to SERAPHIM Software* (keys software to one of six popular chemistry books, around five dollars each), and *Teaching Tips* are also available.

Journals, Newsletters

Several professional journals (Journal of Chemical Education, CHEMTECH, ChemMatters, etc.) contain supplemental information. In addition, teachers are encouraged to refer students to local and current newspapers, television, and magazines to reinforce the interrelatedness of chemistry with the community.

The ACS Educational Division distributes a newsletter that was originally entitled *ChemComments*. It was published twice yearly and contained articles submitted by *ChemCom* teachers sharing ideas and strategies for teaching *ChemCom* lessons. For example, teachers reported on the benefits of scaling down the laboratory exercises, and offered to share scaled-down protocols. Also, *ChemComments* contained updates on workshops and other relevant information. In 1990, ACS incorporated *ChemComments* into a new newsletter entitled *Chemunity*. According to ACS, this was done to achieve more rapid dissemination and reach a wider audience. *Chemunity News* is published five times yearly and is available free of charge from the ACS Educational Division. The newsletter is funded by ACS.

DEVELOPMENT

Creating the ChemCom Text

Planning and development of *ChemCom* began in 1980 and was the result of the coordinated efforts of:

- **A Steering Committee**, chaired by former ACS president, Anna J. Harrison;
- **Staff** composed of W.T. Lippincott, principal investigator; Henry Heikkinen, chief editor; Sylvia Ware, project manager; and Frank Sutman, chief evaluator; and

- **Writing teams**, each of which was to develop one curriculum module. Each team was made up of a unit director experienced in writing classroom materials and three or more high school chemistry teachers. From the inception of this project, the developers regarded the importance of the inclusion of teachers as vital.

With the charge to develop chemistry lessons that introduce chemical concepts and principles on a "need-to-know" basis, and funding from the National Science Foundation (NSF) and the ACS, the staff began writing the *ChemCom* curriculum in 1982. (Lippincott, 1987). Throughout the process, there was extensive evaluation and field-testing. Each unit was reviewed by content and teaching specialists, then introduced into existing courses in a local community for small-scale field-testing. In 1983, social scientists reviewed the curriculum and provided feedback on the presentation of the social issues central to the chemistry lessons. To unify the course and establish the sequence of modules, a synthesis conference was held in the summer of 1984. Participants included members of the steering committee, unit directors, some of the high school teachers who prepared the modules, and the staff. Following the synthesis conference, a revision-writing team of high school chemistry teachers, an editorial advisory committee and content consultants produced the field test version of *ChemCom*. This group also produced a teacher's guide. Industrial and academic chemists verified the chemistry content. Figure 2 diagrams *ChemCom*'s development strategy.

Field Testing

The developers viewed the field-test as the arena to find out whether the philosophy, approach, and content of *ChemCom* would be accepted by teachers and students (Eubanks, 1987). For example:

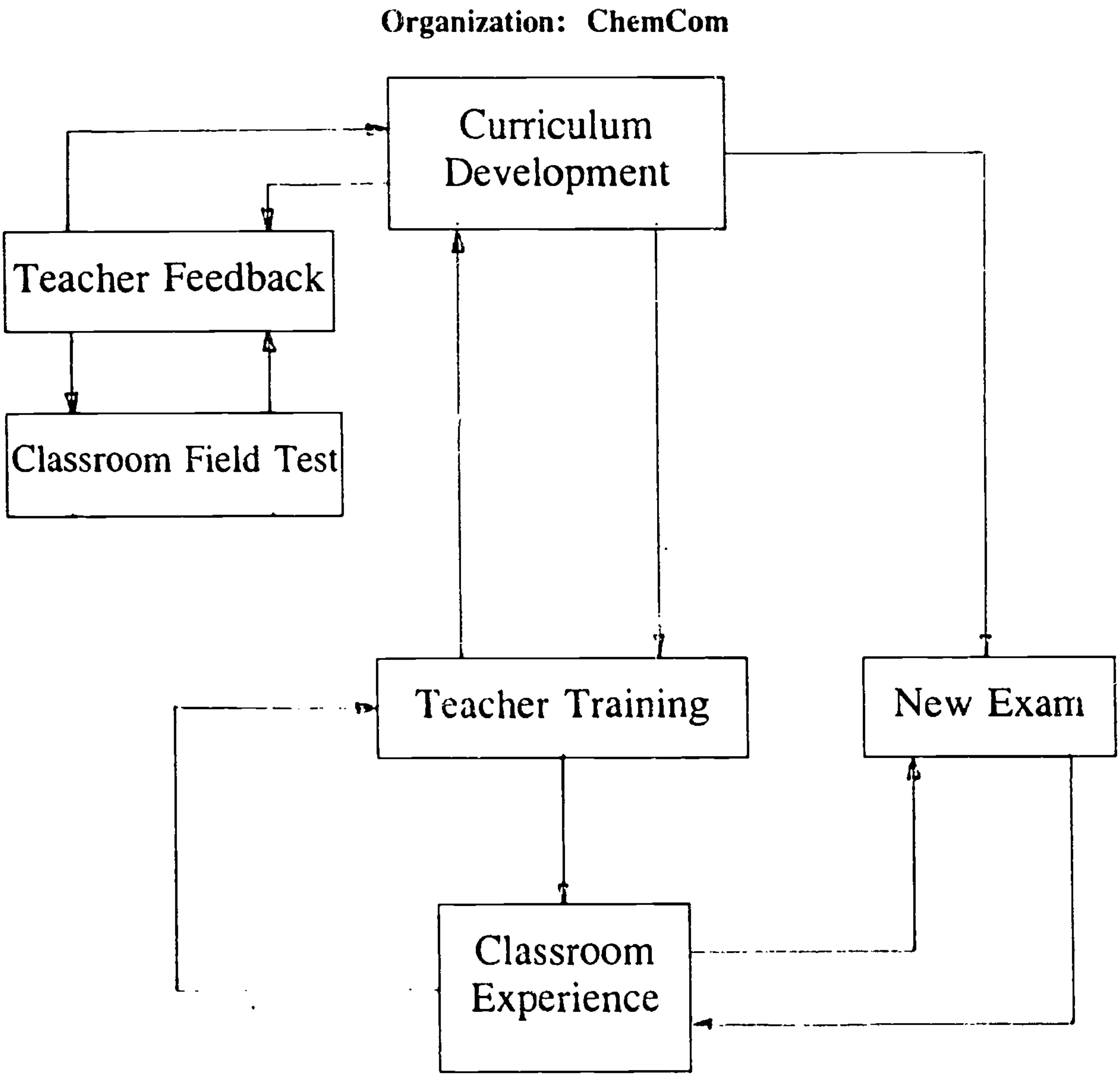
- Would the teachers be willing to yield to student-centered, cooperative learning activities, and relinquish their roles as lecturers?

- Do the social situations used to present the chemistry lessons introduce bias or value judgements not shared by certain student populations?

- Is the material itself good, sound science?

Field-testing took place in a total of 13 states with 61 teachers and approximately 2 900 students from 1985 to 1986. There were two types of field-testing sites: supported or unsupported (Lippincott, 1987). Supported sites included a site director (university chemist) and a group of teachers and students. Teachers participated in training workshops before the field test and met often with the site director to work out problems and share ideas. There were seven supported sites, located in seven states. Each site included a number of field-test schools. In six states, field-testing was conducted at unsupported sites. Teachers taught *ChemCom* primarily from the teacher's manual. These sites were physically distant from the seven supported sites; hence, the teachers received no feedback from the directors and did not participate in workshops. The field test was organized to test the greatest number of demographic variables possible. The seven supported test sites were New York City, Seattle, Shreveport, Houston, Denver, San Diego, and Richmond. These sites included schools from urban, rural, and suburban areas. Students came from rich and poor families and from various ethnic groups; were immigrants and US-born, and attended public and private schools.

Figure 2. Diagram of Chem Com's Development Scheme (Ware. 1991*b*)



Curriculum Emphases:

Everyday coping
Science, technology, and decisions
Scientific skill development

The formal evaluation of the year-long field test was not available for review. However, I. Dwaine Eubanks, the field test workshop director, reported students were uniformly enthusiastic about the course (1987). They learned from the materials and found them appropriate. Teachers generally accepted the *ChemCom* approach; there were some who found relinquishing their authority roles threatening. Field testing also revealed the biggest barrier to *ChemCom* acceptance was teacher acceptance of two key aspects of the curriculum, "everyday coping" (chemistry in every day life) and "science, technology, and decisions" (Ware, 1991*b*).

The teachers worried chemistry presented in the context of every day was not real science. A member of industrial and academic research chemists, however, did not share this concern; they expressed enthusiasm about this approach to teaching chemistry. Interestingly, among chemists who id express reservations about the science content in ChemCom, more academic chemists than industrial chemists raised concerns. Informal reports indicated some teachers from the unsupported sites would have preferred to have a director and tended to think it necessary to supplement *ChemCom* with traditional chemistry lessons.

Following the field-test, the contributing editor wrote a revision. After review by ACS staff members, *ChemCom* was published as a commercial text by the Kendall/Hunt Publishing Company in January, 1988.

Developing the ChemCom Exam

A team of 20 members of the ACS developed a standardized examination. The *ChemCom* test committee consisted of equal numbers of high school and college teachers. All work with *ChemCom* either as teachers or teacher trainers, and many were involved with writing or field-testing the curriculum. Funding for this project came from NSF.

The process began in 1988 and took three years to complete. Two trial tests were developed and distributed to field-test schools. The finalized version of the *ChemCom* test became available in January, 1991. The test was first administered nationwide in the summer of 1991 to 5 350 students. Twenty-six per cent (1 391) of the tests were returned for norming procedures and results showed a normal distribution. No formal evaluations have been conducted; but anecdotal feedback from teachers was generally positive. Also, no formal surveys have been conducted with students; however, students were reported to think the test was fair and they felt adequately prepared to answer the questions.

To assist teachers in assessing their students' progress in *ChemCom* throughout the course, ACS was developing a *ChemCom* test bank (American Chemical Society, 1991). This resource was to contain nontraditional test questions contributed by *ChemCom* teachers. Unfortunately, ACS has discontinued development work on the test bank at this time.

STAFF DEVELOPMENT

Teacher training is essential for the successful implementation of *ChemCom*, according to Sylvia Ware, the program director for *ChemCom*, as it is for the success of any curriculum. For example, to teach *ChemCom* successfully, teachers need training to guide the decision and problem-solving activities. Also, the heavy emphasis on laboratory activities requires the teachers be comfortable with this learning environment.

Teacher training workshops began in summer 1988. They were funded by ACS, NSF, and the chemical industries. For the first three years, the primary purpose of the workshops was to produce a corps of experienced *ChemCom* resource teachers who would serve as multiplier agents. A multiplier agent is a resource teacher who is familiar with the philosophy and content of *ChemCom* and provides inservice programs in his/her own and adjacent school districts. Teachers received ten days of training in one of a total of 12 workshops held over three summers. Experienced *ChemCom* teachers conducted the workshops. During the training, teachers worked in groups and participated in a number of activities. For example, they performed many of the laboratory and decision making exercises in *ChemCom*, engaged in group discussions relating to *ChemCom* content, and reviewed material supporting the course.

As of 1991, 237 resource teachers have been trained. According to the final report of the NSF-funded project for resource teacher training (Ware, 1991*a*), 51 per cent of the resource teachers led in-service training activities in their local areas after attending the workshops. ACS staff stated more were conducted, but not documented. The project staff hoped resource teachers would hold more in-service workshops. It became clear, however, this was unrealistic in light of many logistical and administrative considerations. For example, few administrators were willing or able to schedule week-long training.

As of summer 1991, the purpose of teacher training workshops is no longer to train resource teachers: it is to orient teachers to the philosophy and content of *ChemCom* to support their teaching of the course. Approximately ten week-long workshops are scheduled for each summer until 1994. ACS will sponsor them; the chemical industry, ACS, and profits from text book sales will provide the funds.

In addition to the above teacher training efforts, Kendall/Hunt supported workshops trained approximately 200 teachers and presented *ChemCom* awareness seminars to over 1 000 teachers (Ware, 1990). Also, Kendall/Hunt sponsors *ChemCom* Clubs across the nation to provide support for *ChemCom* teachers in areas where *ChemCom* is heavily used. Each club holds six meetings a year and is hosted by a ChemClub resource teacher. *ChemCom* clubs are considered by the developers to be important support mechanisms for *ChemCom* teachers. The final NSF project report for resource teacher training states teacher support groups "continue to be a major cohesive influence among *ChemCom* teachers in several metropolitan areas." In most cases, Kendall/Hunt underwrites a portion of the clubs' expenses.

DISSEMINATION AND ADOPTION

Types of Students

The primary audience remains as envisaged in 1982 by ACS: college-bound, non-technical students, as well as other bright students. However, many chemistry educators see *ChemCom* as a beneficial supplemental course for science majors as well. Intended to be an eleventh grade course, *ChemCom* also has been introduced at other levels, for example, at community colleges and as an elementary text for teachers. Teachers have adapted *ChemCom* to accommodate slow learners, although the course is not considered appropriate for this group of students. In these cases, teachers cover about half the material.

ChemCom in the United States

Since initial publication of *ChemCom* in 1988, nearly 137 000 copies of the text have been sold (as of October, 1991). Over 250 000 students have taken *ChemCom*. The state of California, which does not require adoption procedures for high school texts, has purchased over 12 000 copies of *ChemCom*. Also, California has paid for teacher training. It has been adopted for use by school districts in Wichita, Kansas; New York City, New York; and Baltimore, Maryland. *ChemCom* has been listed as an approved/supplemental text in Alaska, Illinois, Michigan, Missouri, and Ohio.

Kendall/Hunt conducts all negotiations with state adoption committees. The first edition has been adopted for use in Alabama, Arkansas, Florida, Georgia, Idaho, Indiana, Kentucky, Louisiana, North Carolina, Oklahoma, South Carolina, and Utah. The second edition will be reviewed in 1992 by adoption committees in the states of West Virginia, Texas, Utah, New Mexico, and Indiana.

ChemCom in Other Countries

ChemCom also is receiving international attention. Negotiations are underway for texts to be translated into Russian, Japanese, and Lithuanian. The Russian-language adaptation of the text is being prepared by the Mir Publishing Company. One hundred thousand texts have been ordered and are planned for classroom use by 1993. No field testing has been planned before implementation. In November, 1991, 16 United States teachers trained 140 Russian teachers in ACS-hosted workshops in Moscow. Funding for the workshops came primarily from ACS. The teachers paid half their airfare, and the Mendeleev Chemical Institute provided food, transportation, and lodging. Russia and Lithuania plan to use *ChemCom* as a standard text, and Japan plans to use it as a resource text. Lithuania plans to develop adaptations for its text.

Problems

Some teachers criticize *ChemCom* for not including enough mathematics, or not having sufficient mathematical rigor. *ChemCom* does treat mathematics differently than traditional chemistry curricula to prevent it from being a learning barrier for non-technical students, *Chem Com*'s main users.

No longer available is an electronic bulletin board. Feedback from the 1988, 1989, and 1990 post-workshop surveys (O'Brien, 1990) revealed teachers had a number of problems with the system, including: hardware incompatibility; lack of computer access; lack of modems; little information was available once ChemNet was accessed; noisy phone lines; inability to download information; and, users were disconnected.

There have been failed attempts to implement *ChemCom*. Reasons for failure have not been documented formally. Anecdotal information on failures included the following reasons: 1) inadequate/no teacher training; teachers without the appropriate orientation to the course design have attempted to subvert it and supplement it with material incorrectly; and 2) inappropriate student selection (*ChemCom* is not a dumping ground for hard-to-place students). Also, students need to have high verbal skills to do well in *ChemCom* since it is an interactive course.

COURSES TRIGGERED BY CHEMCOM

ChemCom has been a spring board for the development of several other courses, the details of which go beyond this report, but include:

- *Foundations and Challenges to Encourage Technology-Based Science* (FACETS), an integrated science curriculum for seventh and eighth graders;

- A new ninth-grade program, *Partnership in Technology*, currently being field-tested in New York City; and

- A college-level chemistry curriculum, *Chemistry in Context*, is being field-tested in a total of 19 two-year colleges, four-year colleges, and research universities during 1991-1992. Students are from various ethnic groups and represent different levels of college preparation. Evaluation results will be available in June, 1992.

QUESTIONS FOR FURTHER RESEARCH

This paper is only an interim description of *ChemCom* because the National Center for Improving Science Education plans to continue studying this innovation, subject to funding. Future study plans include intensive field work over the next few years. We close this paper with a summary of questions might be pursued.

1. What are the statistics on *ChemCom* sales? Which states? Which school districts? How many of each?

2. What other kinds of students are taking *ChemCom* in contrast to the kinds of students for whom the developers designed it?

3. What are different kinds of students learning from *ChemCom* with respect to traditional chemistry content, applied chemistry content, laboratory skills, science investigations, and working cooperatively in groups?

4. What kinds of teachers are being assigned or volunteering to teach *ChemCom*?

5. Since some teachers have not found it possible to teach all the Chapters in the *ChemCom* text, which chapters are they using?

6. What instructional differences exist between teachers who have *ChemCom* training and those who don't, and between teachers with access to *ChemCom* support groups and those without access?

7. How does teachers' *ChemCom* instruction change from year to year? If some teachers discontinue using *ChemCom*, what are the reasons?

8. To what extent is teachers' use of *ChemCom* consist with the developers' intent? For example, how extensively do teachers employ the "decision-making" activities and to what extent? Do they add more traditional chemistry topics to the curriculum?

9. How do teachers assess what student's learn from *ChemCom* given the limited assessment strategies in *ChemCom* text? What percentage of *ChemCom* teachers are acquiring and using the ACS developed test?

10. What continuing efforts are ACS and Kendall/Hunt making to have *ChemCom* approved in adoption states and how successful are these efforts? What efforts are being made to get *ChemCom* accepted as a science credit at junior colleges, colleges, and universities?

11. How does the implementation of *ChemCom* in other countries compare to its implementation in the U.S.?

REFERENCES

American Chemical Society (1988). *Chemistry in the Community.* Dubuque, Iowa: Kendall/Hunt. p.4.

American Chemical Society (1988). *Chemistry in the Community: Teacher's guid-.* Dubuque, Iowa: Kendall-Hunt. p.xxix.

American Chemical Society (1990). *ChemCom. Chemistry in the Community. Teacher's Guide.* Kendall/Hunt Publishing Company, Dubuque, Iowa.

American Chemical Society (1991). ChemCom Test Bank Under Consideration. *Chemunity 1,* 1,11.

Berry, K.O. (1988). Learning in the Laboratory Isn't Just an Idea! *ChemComments 1,* 1, 8-9.

Eubanks, I.D. (1987). Testing the ChemCom Product. *Chemunity 8,* 2:14.

Gross, G.R. (1989). Microsizing ChemCom Labs. *ChemComments 2,* 1,6-7.

Lippincott, T. (1987). The ChemCom Story. *Chemunity 8,* 2, 3-4.

O'Brien T. (1988). Bypasses and Barriers to the Implementation of ChemCom. *ChemComments 1,* 1,3.

O'Brien T. (1990). One Year Delayed Post Workshop Survey Results from the Summer 1988 ChemCom Resource Teachers. p. 14. (1991). One Year Delayed Post Workshop Survey Results from the Summer 1989 ChemCom Resource Teachers. p. 18. (1990). One Year Delayed Post Workshop Survey Results from the Summer ChemCom Resource Teachers. p. 19. In Ware, S. (1991) *Final Report. ChemCom Dissemination/Networks.* Grant #TPEP8851139. National Science Foundation: Washington, DC.

Ware, S. (1990) *Chemistry in the Community: Chemistry on a "Need-To-Know" Basis.* International Symposium on the Environment and Chemistry Teaching. p. 5.

Ware, S. (1991*a*). *Final Project Report. ChemCom Dissemination/Networks.* Grant #TPEP8851139. National Science Foundation: Washington, DC. p. 2.

Ware, S. (1991*b*). *Secondary School Science in Developing Countries: Status and Issues.* World Bank Report. p.36.

NATIONAL GEOGRAPHIC SOCIETY'S KIDS NETWORK

A Project of Technical Educational Research Centers

Edward Britton

A SKETCH OF KIDS NETWORK

This upper-elementary school science curriculum was developed by Technical Education Research Centers (TERC) and is published by The National Geographic Society (NGS). The following scenario illustrates the adoption and implementation of Kids Network by a fictitious 5th-grade teacher.

Before . . . .

It's the beginning of the school year and Ms. Lopez, sensitive to her principal's encouragement to incorporate hands-on science this year, is intrigued by a National Geographic Society brochure. It advertises an activity-centered curriculum comprised of units such as **What are We Eating?** *and* **Too Much Trash**. *It sounds like her kids might be really engaged by these investigations of real-world problems. They permit the students to be budding scientists: collecting, analyzing, and communicating data. Ms. Lopez isn't sure what this means in practice, but it would be good to find out what scientists really do. However, an integral part of the curriculum is using the computer and Ms. Lopez is intimidated. Before she discards the brochure, Ms. Lopez notices that free preview kits are available.*

Three weeks later, the preview kits have convinced Ms. Lopez and her principal to spend $475 on **Acid Rain**, *one of seven Kids Network units. The nine-minute videotape showed very active kids and teachers and the 16-page student handbook was interesting. The 50-page teacher's manual detailed exactly how the unit progresses, provided loads of planning information, and had helpful tips that anticipated many of Ms. Lopez's concerns. Thirty pages explained how to use the computer. A floppy diskette let Ms. Lopez try the Kids Network software which was almost no problem at all to use . . . the kids should be able to handle it, like it, and learn a lot! The insurance policy, however, is a National Geographic Society hotline to help with computer problems!*

It's December and Ms. Lopez is preparing to use the six-week Acid Rain unit during January and February. She has spent several hours over the last month reading the materials, trying activities, and setting up the computer. The latter was tedious and trying, especially arranging for someone to get and install a modem, but the school librarian and the district's computer people had been helpful. Now, Ms. Lopez is trying the telecommunications: she puts her computer and modem on a cart and wheels them to the assistant principal's office to connect them to his telephone line. She sends some information from Kids Network and receives an introductory letter from the Acid Rain unit scientist.

Ms. Lopez has had to plan carefully the scheduling of the 12 class sessions for Acid Rain, two per week, because there will be several telecommunications deadlines for sending or receiving information. Each session needs at least an hour: several sessions require a lot more time. Finally, Ms. Lopez is spending a couple of class sessions in December teaching the geography concepts of latitude and longitude and letting the students become familiar with the five features of Kids Network software: graphing, word *processing, recording data, mapping data, and telecommunications. If Ms. Lopez had elected to first conduct another Kids Network unit, **Hello**, then this wouldn't be necessary.*

During . . . .

Week One

The kids love the idea of collecting rain, testing its acidity, and using the computer to communicate with kids who are doing the same thing in other places! Kids Network has assigned Ms. Lopez's class to a research team comprised of twelve fourth- to sixth-grade classes located around the country. Ms. Lopez has the students mark the locations of their research teammates on the wall map, and assigns groups in her class to take turns entering the locations on the computer map as well. The students discuss what acid rain might mean, list questions they have about it, read the student handbook, and discuss a letter from the acid rain scientist. For homework, students take an activity sheet that asks them to get their parents' help in reading labels on food and other products around the house to discover the kinds of acids they contain.

On another day, Ms. Lopez explains Ph to the class. Afterwards, the kids construct a huge pH scale out of poster board and hang it on the wall. An activity sheet guides students to use pH paper to test the acidity of liquids they have brought from home. Students work cooperatively in groups: one student prepares the materials, another tests them, a third student writes down everyone's observations, and a fourth student reports the results to Ms. Lopez. She assigns some art time to let the students draw pictures of household items labelled with their pH, and they attach these to the class's big pH scale.

Week Two

This week the students build rain collectors from common materials like coffee cans and plastic cups. Whenever it rains during the next three weeks, the students will collect rainwater and test its pH. But there are lots of other things to do during the three weeks. Ms. Lopez helps the groups of students to cooperate in organizing and conducting a study of sources in their community of gases causing acid rain, and another study of the prevailing winds patterns for the community. Ms. Lopez is unsettled yet excited about Kids Network. It's so different that hardly any of her usual instructional practices apply. Her only option is just to dive into the uncharted territory. But the experience is truly fascinating to both her and the kids.

Week Three

Students use the word processing part of the Kids Network software to write letters about their community and its sources of polluting gases. Ms. Lopez and a group of students then use telecommunications to send them to their research teammates. On another day, students discuss the examples in their handbook of acid rain's effects on living things. Ms. Lopez then has them model acid rain's effects on non-living things by placing various metals and stones in vinegar.

Week Four

The students observe vinegar's effect on materials and Ms. Lopez leads a discussion to help them generalize these effects to those of acid rain, over time, on building materials. But the most exciting moments, thus far, occur later in the week. Students receive and discuss letters from other teammates describing their communities and sources of acid rain. Also, the students record their pH measurements of rainwater in the computer and analyze them. Student groups vary in their use of different types of *computer graphs to display their data: bar graphs, line graphs, and pie graphs. Later, the students are so excited about sending their data to the teammates that Ms. Lopez wishes her classroom had a telephone line so she didn't have to pick only a few of them to go with her to the office. Ms. Lopez catalyzes a lengthy class discussion during which the students predict the acidity of teammates' rainwater based on their own pH measurements, sources of acid rain in their community, and sources of acid rain in the teammates' communities.*

Week Five

The kids, eager to check their predictions, clamor for Ms. Lopez to obtain the pH results of their teammates. A lively class discussion ensues when the students look for patterns in the teammates' data. The students are so spirited that she has to remind them of rules for discussion. Even John, someone who rarely speaks out, especially during science, gets into the fray and advances an explanation that nobody else has considered for one puzzling set of data. His group decides to compose a letter to the teammates and sends it via the computer. At the end of this session, Ms. Lopez asks the students to predict patterns they might find in the data they shortly will receive from Kids Network that will be compiled from all 500 schools participating in Acid Rain during these six weeks.

Later in the week, Ms. Lopez obtains the comprehensive data set and it comes with a letter from the unit scientist who points out patterns and poses questions. The class debate that follows deeply impresses Ms. Lopez. She is startled to realize that through this process she now understands what scientists do -- work with data.

Week Six

Ms. Lopez distributes the thirteenth and fourteenth activity sheets from the acid rain kit. One advocates quick action to address the acid rain problem and the other advises more study. The former emphasizes the damage caused by acid rain and the latter stresses the social and economic costs of addressing acid rain. She then has each student group discuss the positions, reach a consensus to adopt one of them, and write and send their own position paper to their teammates.

Ms. Lopez sends the Kids Network press release to the local newspaper. A reporter comes and hears the students present their work and watches them demonstrate some of the activities. She is amazed by the reporter's avid interest in her students' work and wonders whether his story will be about her 5th graders' data and conclusions on acid rain or about their ability to contribute to the work of scientists.

KIDS NETWORK: AN INNOVATION

How does Kids Network represent a notable change from other elementary science curricula (i.e., in what sense is Kids Network an innovation)?

- Kids Network employs telecommunications[1] to enable upper-elementary school students across the country and in other countries to exchange scientific data.

- The curriculum fosters new roles for teachers, students, scientists, and computers.

- Kids Network incorporates many features advocated by science education experts to a greater extent than do some other curricula.

Telecommunications facilitate new kinds of science experiences. Students collect data, analyze them, and exchange both their data and their findings with students in other locales. Further, Kids Network sends the students' data to a scientist, an expert on the scientific problem being investigated. This "unit scientist" analyzes the students' data and their analyses and returns the results to the students along with probing questions for them to consider.[2] The following excerpts are from the unit scientist's letter during the field test of the **Hello** unit during which students collected information about pets (Technical Education Research Centers, TERC, 1988:9b):

> Thank you for all the pet data. I hope you had fun thinking about your data and ways to display it. The chart on the next page shows the pet data for all students on the network.
>
> Here are some things to talk about with students in your class and with teammates in your cluster. Geographers would ask if location is related to the types and numbers of pets kids have. For example, are there differences in urban and rural data within your cluster? Does cluster data show differences in pets living in various parts of the United States or the world? Other differences from place to place?

Modern science requires collaboration with other scientists; since the early 1970s scientists have used telecommunications networks to share data and discuss results (Jennings *et al.*, 1986). Thus, students participating in Kids Network conduct the same activities as scientists. They aren't just acting like scientists, they **are** scientists! John Miller, unit scientist for **Acid Rain** and a senior researcher on acid rain for the National Oceanic and Atmospheric Administration, proposed including students' Kids Network data as an appendix to NOAA's 1988 report on acid rain (Julyan, 1988).

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1. Dr. Robert Tinker (1991:5), director of TERC, encourages use of the word "telecomputing," meaning computer-based communication, in lieu of "telecommunications," meaning communication over distance by many means (e.g., telephone, telegraph, etc.).

2. Science Experts On-Line on the McGraw-Hill Information Exchange (MIX) also lets students ask questions of scientists. However, Kids Network systematically sponsors expert-scientist collaboration with hundreds of student-scientists engaged in the same investigation. In 1988, MIX was used in a similar manner. Students around the country reported data to scientists on plant growth activities using fast-growing seeds developed at the University of Wisconsin, today commercially sold as *Fast Plants* (Schrum, Carton, and Pinney, 1988).

Telecommunications have been used previously in public education, but not for projects primarily targeting elementary students. There are regional and national electronic networks or bulletin boards for high school or middle school students that enable them to obtain information or data from a central source (e.g., on-line databases such as Accu Weather) (Parisi and Jones, 1988) or to exchange information with other students on the network (e.g. Compuserve at the national level, and numerous bulletin boards at the local or regional level).

Also, there are other telecommunications-based curricula besides Kids Network that have been used for students' collaborative investigations (Lenk, 1989). The Department of Education funded Wolfe and Berger at the University of Michigan to develop WaterNet, a study by high school students of water pollution in the United States, Germany, and Australia. The Intercultural Learning Network has enabled high school students in the United States, Japan, Israel, and Mexico to learn about different social, cultural, and physical worlds, in part through science investigations (Levin and Cohen, 1985). Elementary and secondary schools have participated in the AT&T Long-Distance Learning Network to collaborate on projects in geography, social sciences, language arts, and science. Kids Network, however, is the only telecommunications-based curriculum devoted to collaborative investigations in science by upper-elementary students.

The new science activities made possible by telecommunications require teachers, students, scientists, and computers to have new roles in the learning process. Teachers must become skilled facilitators of small and large group discussions of scientific issues. Teachers and students learn how to discuss scientific issues on the basis of data. Further, teachers must help students conduct scientific investigations rather than "cookbook" activities. The students must work cooperatively on data collection and analysis. Scientists interact with students about data, treating them as junior scientists. Computers are not used merely as learning machines for drill and practice: they are tools for analyzing data, exchanging data, and communicating.

Kids Network is an innovation also in that it incorporates many of science educators' recommendations for reform, as shown in Table 1. In Kids Network, these features are tightly threaded into the curriculum. Indeed, these features are integral to Kids Network because they are a natural part of conducting scientific investigation, the heart of Kids Network units. In some other curricula, such features tend to be loosely woven into the curriculum design, thus allowing teachers to proceed in their traditional pedagogical mode and ignore the innovative approaches.

A PORTRAIT OF KIDS NETWORK

The Seven Units

The National Geographic Society (NGS) is marketing six Kids Network units for the 1991-1992 school year; a seventh unit, **Solar Energy**, is scheduled to be added during 1992-1993 (National Geographic Society, 1991). Each unit focuses on an environmentally sensitive topic. Funding from Telecommunications Education Trust supported translation of the **Hello** unit into a Spanish version.

Hello! Students collect data about the pets they own and share the information with teammates. Each participating class also sends a letter describing the community so that teammates can begin to explore explanations for different pets in different locales. The less demanding science content in this unit makes it easier to familiarize students with the scientific methods and computer tools used in Kids Network. Students who don't use the Hello unit are still able to participate in other Kids Network units if additional time is allocated to become familiar with the Kids Network computer tools.

Acid Rain. For a description, see the story about Ms. Lopez's class at the beginning of this paper.

Too Much Trash. Students design and implement an in-class collection of trash, sorting and weighing it over a period of days (Julyan, 1990). They graph their findings, calculate the average weight of refuse discarded by each student, and share the data with teammates. A unit scientist helps them analyze the data aggregated from all Kids Network schools. Students learn about waste-disposal methods around the world, debate related science-technology-society issues, and develop plans to reduce, reuse, and recycle their classroom trash. They implement this plan and evaluate its effectiveness.

What's In Our Water? Students determine the sources of their school's tap water, explore how substances get into our water, and determine which ones might be considered "pollutants." They run experiments showing the effects of chlorine on the growth of microorganisms and then test tap water for chlorine levels and nitrate levels. After examining teammates' data with help from a unit scientists, students develop hypothetical water policies for two countries and consider the international implications of water pollution problems.

Weather in Action. Kids investigate dramatic local weather events such as storms and floods, and learn that weather is made up of different elements: temperature, wind, air pressure, and moisture (including precipitation). Students collect key data on temperature and cloud formation. As they share weather data with teammates and the unit scientist, students learn how weather varies across North America and overseas, how workers use weather data in their jobs, and how people are affected by weather.

What Are We Eating? Students test a variety of foods for nutrients, analyze their own lunches for nutrients, and share their data over the network. A unit scientist helps them compare the results from around the world. Thus, students learn how diet varies geographically, and how the same nutrients can be found in different foods.

Solar Energy (In development). Students build solar collectors and measure solar radiation levels. Over the network, kids share and compare data with research teammates and look for patterns that vary with geography. Students also design and build solar devices such as a solar oven.

A $97 "tuition" is required for 120 minutes telecommunications time for 30 students each time a unit is taught. Teachers who repeat a Kids Network unit also must reorder the science supplies for that unit at a cost of approximately $30.

Teachers must acquire some low-cost materials locally. For example, during the **Acid Rain** unit, Ms. Lopez had to buy plastic cups to make rain collectors and vinegar to model the effects of acid rain on building materials. Thus, Kids Network kits differ slightly from some elementary "kits" in the 1960s and 1970s (e.g., Science Curriculum Improvement Study, SCIS, or Science A Process Approach, SAPA) that included virtually all materials even if it meant putting rulers or magnifying lenses in a box.

Instructional Context

Keeping up with the Schedule. Teachers must plan the timing of activities carefully when they teach a Kids Network unit. The NGS holds three sessions for each Kids Network unit three times during an academic year on specific dates to facilitate timely sharing of data through telecommunications (e.g., during the 91-92 school year, **Weather in Action** is offered 9/3-10/25, 3/6-2/28, and 3/23-5/15.). Units last six weeks (plus two more weeks for teacher preparation) and must be ordered two months prior to their beginning date.

Table 1

Kids Network's Curricular Features

Curricular Feature	Brief Description
Student activities are **investigations** rather than cookbook exercises.	Students are given the problem but they help design the materials and methods of investigation, and analyze the data.
Investigations are **engaging real-world problems** rather than contrived or context-free activities.	All 7 Kids Network investigations are described in the next section of this paper.
Cooperative learning is integral to investigations.	Students develop interpersonal and organizational skills as they work in groups.
Units address **science-technology-science (STS)** issues.	Ms. Lopez's class surveyed their community to determine sources of acid rain and later debated their position paper on how to address the acid rain problem locally.
Students experience an **interdisciplinary** curriculum involving geography, mathematics, social studies, language arts, and possibly music or art.	Mathematics includes statistics, a recommended but rarely treated topic in science education curricula. For language arts, Ms. Lopez's students enjoyed writing teammates about their data. For art, Ms. Lopez's students made drawings of household items.
Students acquire **new computer skills**.	The skills are telecommunications, recording data, and displaying data in computer graphs and on computer maps.

Unit Materials: Contents and Costs

Each Kids Network unit costs between $325 and $375 and includes these materials:

- a teachers handbook (approximately 50 pages)
- reproducible student activity sheets (approximately 15)
- three wall maps (U.S., North America, World)
- 15 student handbooks (approximately 15 pages each)
- computer software with a user manual (approximately 30 pages)
- some science materials needed for investigation (e.g., pH paper)

TERC reports that teachers have had mixed reactions to the telecommunications deadlines within a unit. Having an unalterable schedule limits their options for spending the amounts of time they perceive to be appropriate for their students on specific activities. Further, when some aspect of a topic piques the students' or teacher's interest, teachers do not have the flexibility to further explore that topic in depth. The deadlines are worth adhering to, however, because sharing data with kids in other schools is one of Kids Network's principal appeals to students and facilitates new kinds of learning. Moreover, some administrators have felt that, because deadlines gave them some sense of where teachers should be in their instruction, the deadlines have helped them monitor and support teachers' efforts.

More Time for Science. Students involved in a Kids Network unit spend more class time on science than students in many other fourth- to sixth-grade classrooms. In the 1985-1986 National Survey of Science and Mathematics Education, teachers of grades four to six indicated they spent an average of 28 minutes per day on science (Weiss, 1987). Kids Network units comprise two class sessions per week, each taking at least 60-90 minutes.[3] Because Kids Network integrates other subject areas with science, however, teachers often assign additional time for Kids Network from these areas. For example, Ms. Lopez assigned art time for making pH posters and language arts time for her students to compose letters to their teammates. Forty percent of them reported spending more time on science during Kids Network than during their usual science instruction.

Getting Equipment and Setting It Up. This aspect is the greatest hurdle for teachers to surmount when first preparing to use Kids Network. First, teachers must have at least one computer in their classroom. Although many U.S. elementary schools have computers, teachers often must arrange to move one into their class for the six-week Kids Network units. Having more computers is desirable: a single computer severely limits the amount of time that students can use Kids Network's word processing software for composing letters to teammates, one of the most time-consuming student activities. An additional impediment is that Kids Network software only operates on Apple IIGS computers. However, NGS and TERC have contractors adapting the software so that in the Fall of 1992 it will also operate on Macintosh computers and IBM PS/2 computers or compatibles.

Second, the computer must have a modem for telecommunications. Many elementary teachers are unfamiliar with modems, and few have used one prior to Kids Network. They or someone else they find to help them must figure out where and how to order one and install it on the computer when it arrives. Third, in order to use the modem, the teacher must have access to an outside telephone line. Since few elementary teachers have phone lines in their classroom, they must arrange to get one installed. Otherwise, they must move their equipment to wherever an outside line is available in the school. (Ms. Lopez had to cart the computer to the assistant principal's office for the telecommunications sessions.) Fourth, a dot-matrix printer is highly recommended.

The burden that these obstacles represent to teachers depends in part on what help is provided by school and district administrators and district computer specialists. TERC found that even many teachers in districts that did have a computer specialist obtained technical assistance from NGS's hotline (a toll-free service). Administrators can be a tremendous help in acquiring equipment and arranging for their installation.

Now that many teachers are enthusiastic about Kids Network, it is easy to forget that TERC, NGS, and NSF had to discount the lack of appropriate computer equipment in schools (particularly modems and

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3. TERC originally envisioned four-week units requiring only 90 minutes per week. From field tests of the first unit, however, TERC learned this was too short a time period for teachers to carry out all the unit activities.

appropriate telephone lines, but specific types of computers as well) and forge ahead in the belief that Kids Network would motivate educators to acquire the needed equipment. This scenario presents the classic "chicken and egg" dilemma faced in the initial application of any new technology in education. Developers are reluctant to create educational products that depend on new technology because the schools don't have it. Schools are reluctant to spend substantial monies on new equipment because few products exist that use it. This impasse is broken when a developer creates an educational product with such great appeal that schools will get the equipment needed to use it. Once they do, more products can be developed that make use of the equipment.

Further Preparations. Before teachers make any unit-specific preparations, they must acquire and set up the necessary equipment. Having made this one-time effort, however, they must then (1) make preparations for the hands-on investigations, (2) become familiar with Kids Network software, and (3) develop skill in facilitating classroom discussions about both scientific issues and data interpretation. Because preparing for and conducting them require more work than traditional science instruction, Kids Network's project director as well as a district science supervisor heavily involved in field testing believe that most teachers will use these units as supplementary curriculum materials. In their view, the majority of teachers will not be able to make the effort needed to use Kids Network units continuously throughout the year.

The amount of work that each of the above tasks represents varies with teachers' prior experiences. Collecting and organizing materials for Kids Network's science activities will not be an increased burden for teachers who have conducted hands-on science activities previously. Teachers with such experience are in the minority, however, since elementary teachers spend very little time on any kind of science, and many more spend whatever instructional time they do allot to science on describing and discussing numerous basic facts. Teachers' prior experiences with computers and their attitudes toward them will affect the amount of time needed to become familiar with Kids Network's software. The developers tried to address this problem through minimizing the number and complexity of commands with which users must become familiar. As a result, even teachers with no prior computer experience generally have been successful in using the software.

Teachers used to assuming an authoritative role during class discussions often have difficulty facilitating discussions in which students debate issues, define variables, describe data, and draw inferences and conclusions from data. Teachers must elicit students' ideas with probing questions, make these ideas the foundation of discussions, prompt students to support their ideas with data, etc. For example, Julyan (1989:14) reports the discussion that arose during the **Hello** unit when students tried to agree on what is and what is not a pet:

> Why do you think this other class reports twice as many pets as our class? How would you define a pet? Is an ant farm a pet? How about a dog that you are boarding indefinitely with relatives? Do a lot of the other students live on farms? Would you consider a pig a pet if it later became Sunday dinner? Do you have to do things with an animal for it to be counted a pet? Does feeding an animal make it a pet?

Such discussions are considerably more sophisticated than traditional classroom discourse; Kids Network has made helping teachers with them a major component of its teacher training efforts.

A Supplementary Curriculum. Even though there are more than enough Kids Network units to take up the entire school year, the curriculum has been supplementary to date for the reasons noted above, and because schools cannot use textbook funds to purchase it. Kids Network is not eligible for adoption under most states' current guidelines. However, some states are updating these to include technology-based materials. For example, California's 1992 guidelines encourage materials other than textbooks; hence NGS plans to submit Kids Network for adoption consideration in this state.[4] Thus, in the near future, schools in some states may be able to acquire Kids Network kits with their state allocation of funds for textbooks. Kids Network's telecommunications charges, however, most likely would still have to be covered by monies other than state textbook funds. Since many poorer school districts have extremely limited supplementary funds, they may find it difficult to acquire Kids Network without external financial assistance. Further, poorer districts are less likely to have the computers, modems, and telephone lines needed for Kids Network. The NGS and TERC are discussing ways of addressing this problem of equal access.

DEVELOPMENT OF KIDS NETWORK

In 1986, the National Science Foundation awarded a four-year, $2.6 million grant to TERC to develop Kids Network in partnership with the NGS, who committed matching funds. In fact, the last three of the seven Kids Network units were completed with NGS funds. Apple Computer, Inc., donated close to $400 000 worth of computer equipment for use in the field tests. Development comprised two main tasks: (1) creating the software to be used in each unit, and (2) developing the seven curriculum units.

Software Development

TERC staff had to develop software to manage all the data sent by students around the country. Further, they customized five kinds of software tools for students to use during Kids Network units: (1) features for displaying data in graphs, (2) features for displaying data in maps, (3) word processing features for composing letters to teammates, (4) tables for entering data, and (5) telecommunications features for sending and receiving letters and data. TERC also designed software to integrate the five features into a single package that was user-friendly for elementary school students. Although the software was developed up front, it also had to be tailored for each curriculum unit. For example, the computer specialists designed different tables to accommodate the varying types of data gathered in different Kids Network units. One lesson learned by Kids Network's project director was that "it is a waste of time to field test units unless the software is ready" (Julyan, 1992). Otherwise, teachers are unlikely to give adequate feedback on instructional aspects of the unit because they are preoccupied by frustrations with bugs in the software. This brief account of TERC's software development effort hardly deals with technical difficulties: this phase of the project was a major effort.

TERC's original goal was for software to run on Apple IIc or IIe equipment, since these computers are very common in schools. When these models couldn't adequately handle some of the operations, however, the software had to be designed for the Apple IIgs. This model is rather uncommon in schools, hence the need for Apple to donate computers for the field tests. Apple's Macintosh computer has essentially replaced the IIgs, hence NGS is having the software adapted to run on the Macintosh. As noted, to increase further the number of schools that can use Kids Network, TERC is also having the software adapted to work on IBM computers and compatibles.

Evolution of a Unit

In addition to creating software, the Kids Network project had to create curriculum units. The first development step was to identify research projects that were of current interest, suitable for young children, compelling for most students, and that capitalized on telecommunications and incorporated

4. California's criteria for adoption of materials for science instruction are discussed in this volume.

geography. Further, measuring techniques had to be available that allowed students to collect valid data reliably. Meeting as many of these criteria as possible proved to be quite difficult. In the original **Hello** unit, for example, students collected information about birthdates and birthplaces. The developers thought this information would fascinate children; it didn't, so TERC dropped this part of **Hello**. As TERC initially explored each new topic, they contacted a total of 20 to 40 scientists, educators, and experts in science education for guidance. The scientists worked in a variety of settings including the federal government, state agencies, the private sector, and higher education. Thoroughly mining the scientific community for ideas paid dividends. One European scientist, for example, suggested an economical water analysis technique that is rarely used in the United States, and it became part of **What's in Our Water?** The rest of the development process is briefly described (TERC, 1991:4-5):

> Midway through development, TERC and NGS staff together agree on the most scientifically, pedagogically, and commercially appropriate direction for the unit. Development ends with a field test version of the unit manuscript. Revisions and an evaluation summary are shared with the staff at NGS. Together, staffs from both organizations agree on the changes that appear in the final manuscript. During the publication phase of the unit, NGS staff edit the unit materials developed by TERC and propose to TERC staff an outline, pictures, and text for the Kids Handbook. The final materials for each unit are approved by both TERC and NGS.

INTERNAL EVALUATION OF KIDS NETWORK

During the development of each Kids Network unit, TERC conducted a field test of the materials. Additionally, NGS conducted a market survey of 500 teachers who participated in the first commercially available session of **Acid Rain**. Kids Network's project director is not aware of any published external research on the use of Kids Network, and staff of the National Center for Improving Science Education did not locate any primary literature about this innovation. TERC's field test methods and results, discussed below, were obtained from TERC's four annual reports on Kids Network (TERC, 1987, 1988, 1989, 1991).

Field Test Methods

TERC conducted a methodical and extensive field test of each Kids Network unit (TERC, 1991:5):

> During the field test phase of the unit, staff collect data from no fewer than 30 classrooms. Sites are selected for participation based on two criteria: a teacher's involvement in at least one other Kids Network unit and a geographically diverse distribution of classrooms. Sites include inner city, suburban, small town, and rural schools with a broad ethnic and socioeconomic mix. Evaluation data include weekly questionnaires and classroom observations in two or three local sites (greater Boston area). The weekly questionnaires are requested via electronic mail. Teachers are also asked to complete a final post-unit questionnaire.

Ninety per cent of the teachers returned the post-unit questionnaire, but only 60 to 80 percent of them returned two or more of the six weekly questionnaires. The classroom observations involved visits to each of the three or four local schools during every week of a unit. Researchers took field notes, interviewed each teacher, and briefly interviewed some students at each site (a total of about 20 students). About 200 students were given pre- and post-tests to determine what they had learned. The first two units, **Hello** and **Acid Rain**, also involved a second, larger field test: 200 schools in all 50 states as well as 11 foreign schools.

The field tests addressed four questions: (1) How did teachers use the unit materials? (2) What problems did they encounter? (3) What were teachers' perceptions of both the units and their students' interest and learning? (4) What did students learn? Findings about the first two questions have been discussed above and can be summarized as follows:

- Teachers spent as much or more time on science during Kids Network units than during their usual science instruction. They were willing to use time usually allocated for other subjects because Kids Network is an integrated curriculum.

- Teachers had mixed reactions to telecommunications deadlines, disliking the constraints they imposed against expanding activities as necessary, but appreciating the appeal of working in concert with classes in other locales.

- Obtaining, setting up, and using equipment (particularly for telecommunications) was a lot of work. However, almost all teachers overcame these barriers.

The latter two questions are discussed below.

Teachers' Perceptions

Most teachers felt that Kids Network promoted positive student attitudes toward scientific investigation and helped them understand it. About 90 per cent of field test teachers said they would use Kids Network units again. The data in Table 2 show that teachers believed students' experiences during the **Weather** unit promoted interest in science and helped them learn scientific investigation processes. Teachers' responses were similar (within 10 per cent) when the same or parallel questions were posed about two other units. Teachers felt students also were learning science content as shown data in Table 3. Ninety-five percent of the respondents to the NGS market survey rated Kids Network as excellent or good. Sixty-five percent of these teachers had to either purchase or borrow a modem in order to use Kids Network. Forty percent of them reported spending more time on science during Kids Network than during their usual science instruction.

Student Learning

TERC staff reported that "teacher assessment of what students learned tended to be very positive. However, there is some discrepancy between the teacher assessments and student performance on paper and pencil tests" (1989:11). Most students could use materials correctly, e.g., reading a compass or using pH paper. However, fewer students (25 to 40 per cent of them) improved in their ability to represent a given data set as histograms or line graphs, to identify patterns in data, or to interpret mapped data. TERC offered the following considerations about the discrepancy between these findings about student learning and teachers' perceptions of it (1989:14):

- Teachers are impressed with students' interest and engagement, but these do not guarantee increased understanding of concepts;

- Some student gains in scientific process may not be assessed adequately by paper and pencil tests.

- Given these considerations, it is heartening to find that even after a short, six-week experience, students are able to demonstrate gains, however modest, on a written test.

Table 2

Percentage of Teachers responding "A Great Deal" or "Quite a Bit" to Questions posed about Student Interest and Learning during Kids Network's Weather Unit

Student Interests	
Increased student enjoyment of science	89
Promoted students' interest in science	87
Promoted students' interest in weather	84
Promoted students' interest in geography	77
Encouraged students to get involved in scientific investigation	70
Student Learning About Scientific Investigation	
Increased student observation skills	97
Helped students develop map-reading skills	85
Helped students work together as a group	89
Helped students see science as a collective enterprise, rather than an individual one	79
Helped students develop data analysis skills	86
Helped students understand how to pose scientific questions	50

Table 3

Percentage of Teachers who believed Students learned "A Great Deal" or "Quite a Bit" about Science Content during Two Kids Network Units.

Weather Unit	
Increased student understanding of temperature scales	84
Increased student understanding of compass bearings	80
What's In Our Water?	
Increased student understanding of unsafe lead levels in water	95
Increased student understanding of corrosion	83
Increased student understanding of pH scale	96
Increased student understanding of relationship between pH and lead level in water	82

Kids Network materials provide teachers with only limited guidance on assessment of student learning. Student responses on Kids Network activity sheets (about 15 per unit) help teachers discern student learning. Teachers' manuals, however, give little direction to teachers for monitoring student progress (e.g., only three sentences in the 40-page manual for **Acid Rain**). Perhaps teachers' observations of students vigorously engaged in science investigations distort teachers' appraisals of student learning because there is insufficient assessment of the latter. Regarding the last two points, above, the encouraging results about student learning obtained thus far suggest an opportunity and need for further research. Researchers should employ assessment methods other than paper and pencil tests, or in addition to them, to probe student understanding.

IMPLEMENTATION OF KIDS NETWORK

As of fall 1991, 250 000 students in 8 000 schools have used Kids Network. Participants were located in all 50 states and 20 countries; schools in 15 additional countries have expressed interest in using Kids Network in 1992. Many dissemination activities spurred this rapid and extensive implementation of Kids Network since the first session in 1988:

- word-of-mouth sharing by field test teachers,
- presentations by TERC and NGS at teacher conventions and other meetings,
- articles by TERC in educational publications,
- NGS promotional mailings, preview service, and hotline service,
- NGS presentations within some states,
- promoting Kids Network with press releases, and
- teacher training by NGS, TERC, and others.

From the start, many teachers involved in field tests were enthusiastic about Kids Network and spoke about it with colleagues. Their sharing of experiences as well as phenomenal press coverage (discussed below) created an early and growing demand for Kids Network. This demand was part of the reason that TERC expanded a second field test of **Acid Rain** from 30 schools to 200 schools. Also, TERC and NGS worked together to advance the commercial release of **Acid Rain** by a year.

Both TERC and NGS carried out standard steps to disseminate Kids Network. TERC staff made presentations about Kids Network at National Science Teachers Association conventions, and NGS exhibited it. Presentations also were made for science education leaders on several occasions, e.g., during a science education committee meeting at the National Research Council (Julyan, 1988: October) and an education technology conference for state science supervisors (Julyan, 1987: September).[5] TERC staff wrote articles about Kids Network in TERC's own periodical, *Hands On* (Julyan, 1990), as well as *Science and Children* (Foster, Julyan, and Mokros, 1988), and *Classroom Computer Learning* (Julyan, 1989).

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5. This may have been a particularly strategic conference at which to present Kids Network. Even at this early date, 34 out of the 35 state science supervisors in attendance had prior awareness of Kids Network, and half of them had observed classes in their states where field tests were being conducted. This conference, sponsored by NSF, made state science supervisors familiar with science education innovations in the belief they might be active, under-utilized disseminators. A follow-up study on one of the innovations presented during this conference showed that 80 per cent of the participating supervisors conducted from three to twenty activities to disseminate it (Britton, 1991).

NGS has promoted Kids Network with four mass mailings, a preview service, and a technical assistance hotline. In 1990, NGS sent its first Kids Network catalog to 77 000 educators. Since then, NGS has updated the catalog twice per year and mailed it to from 5 000 to 8 000 previous purchasers each time. Further, NGS has an arrangement with Karol Media to loan preview kits to prospective buyers (described in the vignette about Ms. Lopez). Teachers can try Kids Network software, inspect a teachers manual, and view a 9-minute videotape. Certainly, many elementary teachers are likely to perceive several Kids Network features as novel: extensive computer use, a new use of computers (telecommunications), activity-based science, and a more facilitative role for the teacher (particularly facilitating discussions). The preview kits familiarize teachers with these features and reduce the perceived risk. Researchers who have studied the dissemination of innovations have concluded that potential adopters are more receptive if they perceive the innovation to have "trialability," i.e., they can try an innovation with minimal risk (Rogers, 1983).

The NGS technical assistance hotline also provides some assurance for prospective users. NGS already includes a 30-page manual on use of equipment and software, but the availability of the hotline further assures teachers that they can successfully obtain, set up, and use the equipment needed for Kids Network. TERC reported that more than 5,000 teachers used this service from the spring of 1990 to the spring of 1991 (TERC, 1991). Most calls related to telecommunications issues; others dealt with questions about ordering, software, and equipment.

Phenomenal Press Coverage

TERC provided field test teachers with a press release and hoped that the local press would be interested. Providing teachers with press releases is a sophisticated dissemination strategy that was little used by projects during NSF's curriculum initiatives of the 1960s and 1970s. In this case, the response was astounding: the Kids Network has been covered internationally in over 1,000 stories on television and radio and in newspapers (TERC, 1991). Articles have appeared in small newspapers, metropolitan newspapers (e.g., *New York Times*, *Chicago Tribune*, *London Times*, etc.), and national magazines (e.g., *Newsweek*, *Electronic Learning*, etc.). Broadcasts have been on local and national programs (e.g., on the British Broadcasting Corporation, *Good Morning America*, *Chronicle*, etc.).

Julyan (1992), Kids Network project director, reports that for many teachers, this phenomenal press coverage was an affirming experience. It provided an external appraisal that Kids Network activities were innovative, and teachers were amazed that the scientific community and the general public were interested in their students' science investigations.

Teacher Training

Teacher training also has promoted Kids Network's dissemination. In some cases, TERC and NGS were invited to present the curriculum to key staff of state Departments of Education (e.g., California and Florida). Various government agencies and private groups have sponsored workshops: The Pacific Telesis Foundation funded workshops in California to train personnel from three disadvantaged schools; the Illinois State Board of Education funded workshops in that state; and the regional BOCES (Boards of Cooperative Educational Services) in New York sponsored some teacher training. In states where TERC and NGS have done the most training, sales of Kids Network doubled or even tripled.

TERC and NGS developed a kit that experienced Kids Network participants can use to train teachers:

- a 43-minute videotape,
- worksheets for computer activities

- a software demonstration disk and guide
- a data set from an actual Kids Network research team
- science activity sheets, and
- suggestions offered by teachers experienced with Kids Network.

The kits also provide trainers with sample workshop agendas and instructions for using the above materials. The videotape familiarizes teachers with four topics: (1) Kids Network's innovative curricular features; (2) obtaining and preparation to use computer-related equipment, science materials, and community resources; (3) classroom management issues related to students' experiments and group work; and (4) facilitating classroom discussions.

During the 1990-1991 academic year, TERC sent a field-test version of the training kit to 62 potential trainers in 27 states. Thirty-four of them held 60 workshops for a total of three thousand teachers, principals, superintendents, district science specialists, and other educators. Eighteen trainers gave feedback: ninety percent of them rated the kits as "essential" or "very helpful." TERC and NGS are discussing future strategies for providing teacher training and making the training kit available Future efforts to study Kids Network's training initiatives might investigate what factors influenced trainers to use or not use the training kit. Additional attempts to get feedback from trainers who did hold workshops also would be useful. Perhaps information could be collected as well from workshop participants.

A "TRIAD" SUCCESS

The Materials Development Division of the National Science Foundation's Education and Human Resources Directorate[6] originally funded Kids Network as part of a program known as the "Triad" projects. Proposers had to submit development plans that included three major players: the developer, a publisher, and school systems. The project had to have a prior commitment from the publisher to participate in the development of curriculum products and to market them afterwards.

The Triad program's goal was for greater distribution of NSF-sponsored curricula for elementary science than was achieved in the 1960s and 1970s. The program sought to promote this by earlier and more formal involvement of publishers. Some NSF-supported curriculum developers in the 1960s and 1970s completed their products and then tried to secure a publisher, sometimes unsuccessfully. The lack of success was particularly frequent at the elementary level. However, some curriculum developers believe that earlier involvement of publishers, with their primary interest in marketing, might inhibit developers from producing the most innovative products. Under the Triad program, some new publishers became involved in science curriculum development, e.g., National Geographic, and Sunburst Communications.

Kids Network appears to have benefitted from the developer-publisher relationship between NGS and TERC. Because NGS participated in decisions throughout the development of units, it was better able to quickly and knowledgeably market them upon their completion. Also, NGS input during development may have enhanced their marketability. NGS produced high-quality print materials, packaging for kits, and brochures. The TERC-NGS relationship may not be a key determinant of Kids Network's success, but further study of the benefits and liabilities of this relationship could help policy makers decide how best to foster productive publisher-developer relationships in future curriculum initiatives. To address this issue more completely, however, researchers also would need to study other Triad projects, some of which ran into serious publisher-developer disagreements.

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6. At the time Kids Network was funded, this NSF directorate was called Science and Engineering Education (SEE).

Next Phase: Kids Network for the Middle Grades

The National Science Foundation recently has funded TERC to develop nine Kids Network units for the middle grades. NGS again is providing matching support. TERC will enhance the software by using a more complex programming language to create powerful data tables and map displays. Also, data collection will be scheduled earlier in the units in order to increase the time available afterwards for students' analysis of data and sharing of results.

ISSUES FOR FUTURE RESEARCH

This paper is only an interim description of Kids Network because the National Center for Improving Science Education plans to continue studying this innovation, subject to funding. Future study plans include intensive field work over the next few years. We close this paper with a summary of research questions that might be addressed.

1. How much science content and what types of content do students learn from Kids Network?

2. What skills do students learn for scientific investigation, e.g., knowing how to display and interpret data?

3. Where is Kids Network used? Which states? How many entire districts are using Kids Network versus individual schools? Similarly, how many entire grade-level faculties versus individual teachers? What kinds of schools/What kinds of teachers? What are the differences in use?

4. How many Kids Network units do teachers use during a school year?

5. What changes do teachers make in their instructional practices during successive uses of Kids Network activities?

6. What impact does training have on teachers' implementation of the curriculum?

7. What is the difference between schools/classes/teachers that have institutionalized KidsNet and those where it is marginal or has been dropped?

8. How do TERC and National Geographic address the financial barrier that limits the ability of poorer schools to obtain and use Kids Network?

9. What changes will TERC and NGS make in the new middle school curriculum as result of their experience with the elementary curriculum?

10. What has made the working relationship between TERC and NGS productive? What changes does each party advocate in the relationship?

REFERENCES

Britton, E. (1991). *Dissemination by State Science Supervisors of a CD-ROM Disc for Innovation in Curriculum Planning.* Doctoral dissertation, University of Florida, Gainesville.

Foster, J., Julyan, C., and Mokros, J. (1988). The National Geographic Kids Network. *Science and Children*, 25, 8, 38-39.

Jennings, D., Landweber, L., Fuchs, I., Farber, D., and Andrion, W. (1986). Computer networking for scientists. *Science*, 25, 8, 38-39.

Julyan, C. (1992). Private communication.

Julyan, C. (1991). Developing network-based curricula. *Proceedings of the Consortium for Educational Computing*, 2. Cambridge, MA: Technical Education Research Centers.

Julyan, C. (1990). Lunchroom garbage: Findings from student-scientists. *Hands-On*, 13. 10-13.

Julyan, C. (1989). National Geographic Kids Network: Real science in the elementary classroom. *Classroom Computer Learning*. 10, 2, 14-18.

Julyan, C. (1988, October). Messing about in science: participation not memorization, *High School Biology: Today and Tomorrow*. Conference held by the National Research Council, Washington, DC.

Julyan, C. (1987, September). Kids Network, *CD-ROM Conference for State Science Supervisors.* Conference held at the University of Florida, Gainesville, FL.

Lenk, C. (1989). Doing science through telecommunications. In J. Ellis (ed.), *1988 AETS Yearbook: Information Technology and Science Education.* Columbus, OH: ERIC Clearinghouse for Science, Mathematics, and Environmental Education.

Levin, J., and Cohen, M. (1985). The world as an international science laboratory: Electronic networks for science instruction and problem solving. *Journal of Computers in Mathematics and Science Teaching*, 4, 1, 33-35.

National Geographic (1991). *1992 Educational Technology Catalog*. Washington, D.C.: Author.

Parisi, L., and Jones, V. (1988). *Directory of Online Databases and CD ROM Resources for High Schools.* Santa Barbara, CA: ABC-CLIO.

Rogers, E. (1983). *Diffusion of Innovations.* New York: Free Press.

Schrum, C., Carton, K., and Pinney, S. (1988). Today's tools. *The Computing Teacher*, 15, 8, 31-35.

Technical Education Research Centers (1991). *Kids Network: Final Annual Report.* Cambridge, MA: Author.

Technical Education Research Centers (1989). *Kids Network: Year 3 Annual Report.* Cambridge, MA: Author.

Technical Education Research Centers (1988). *Kids Network: Year 2 Annual Report.* Cambridge, MA: Author.

Technical Education Research Centers (1987). *Kids Network: Year 1 Annual Report.* Cambridge, MA: Author.

Tinker, R. (1991). *Technology and the National Clearinghouse for Mathematics and Science Education.* Washington, D.C.: OERI/FIRST, U.S. Department of Education.

Weiss, I.R. (1987). *Report of the 1985-86 National Survey of Science and Mathematics Education.* Research Triangle Park, North Carlina: Research Triangle Institute.

PROJECT 2061

A Project of the American Association for the Advancement of Science

Martha Lynch, Edward Britton

INTRODUCTION

Project 2061 is a long-term initiative to reform science, mathematics, and technology education.[1] The reform effort entails developing a vision for what students ought to know in science, mathematics, and technology, developing an appropriate framework, and linking it to what the educational system should provide students from kindergarten through grade 12 in science, mathematics, and technology. Model curricula and recommendations for change within the school infrastructure are envisioned as part of the reform effort. In addition, the developers are considering what strategies will sustain the reform effort beyond the project itself. This includes establishing a strong base of public, political, governmental and professional support.

Project 2061 began in 1985 under the auspices of the American Association for the Advancement of Science (AAAS). As a leading general scientific society with a large membership and affiliated scientific and engineering societies and academies of science, AAAS carries out a number of activities to advance science and science education. The Association has obtained funding for *Project 2061*, thus far, from the Carnegie Corporation of New York, the Andrew W. Mellon Foundation, the John D. and Catherine T. MacArthur Foundation, International Business Machines Corporation (IBM), the National Science Foundation, the U.S. Department of Education, Pew Charitable Trusts, and participating states. The project is overseen by the National Council on Science and Technology Education, chaired by Howard University President, Franklyn Jenifer; the council has 36 members including educators, scientists, and representatives of public groups.

The title of the project is indicative of its philosophy. The year it began, Halley's Comet neared the earth's surface: the comet is predicted to return in roughly one human life-span, 76 years, or the year 2061. According to the developers, this coincidental time frame is a reminder that education is for a lifetime. The full title of the project is *Project* 2061: Education for a Changing Future.

The project work is planned in three phases. In Phase I, the National Council on Science and Technology Education (an AAAS board that guides *Project* 2061) established the intellectual framework for the achievement of scientific literacy. During this process, the council drew on reports from five independent scientific panels and was advised by consultants and reviewers representing science, engineering, mathematics, history, and education. The work from this phase was published in 1989 as *Science for all Americans* (SFAA), accompanied by five panel reports addressing specific fields. In *SFAA*, the council put forth a set of recommendations, or "learning goals," that establish what knowledge, skills, and attitudes high school graduates should have acquired from their educational experience.

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1. Information for this case report was obtained from interviews with Project 2061 staff, Jo Ellen Roseman, Andrew Ahlgren, Sheila Harty, Patricia Bourexis, Ellen Chodosh, Oxford University Press, as well as printed materials on Project 2061.

Phase II consists of four components: Design of curriculum models by teams of teachers, devising blueprints for action, that is, recommendations for changes within the educational system to support implementation of the curriculum models; production of a consensus document to be called *Benchmarks*, to delineate what students should know at select points as they progress through the K-12 curriculum; and disseminating information and forming linkages. The second major report of *Project* 2061, *Designs for Change*, is planned to be an integrated report on reform reflecting the work done in Phase II. It will contain the final curriculum models, *Benchmarks*, and information about the blueprints. This report is expected to be available in 1993.

The efforts of Phases I and II are intended to culminate in Phase III. This phase is designed to be a major campaign to foster the implementation of the model curricula and related reforms in school districts across the nation. All 50 states, all 80,000 schools, and all 50 million students are to be targeted. Phase III is conceived as a long-term endeavor expected to take a decade or more. However, the developers envisage short-term indicators of success along the way. These indicators will include the number of schools using the recommendations of *SFAA* as guidance in their own reforms efforts and adoption and implementation of model curricula as they become available. Such short-term results are seen as paving the way for the reforms necessary to achieve the ultimate goal: science literacy for all Americans.

What makes *Project* 2061 an innovation? According to the developers, the project is comprehensive, integrative, and relies heavily on teacher input. The developers believe that the following aspects of the project set it apart from other educational reform efforts:

- It represents a long-term, multi-phase approach to reform, with substantial time allotted for thorough preparation.

- Science education is defined to include all of the natural, social, and behavioral sciences; mathematics; and technology.

- Equity concerns are central to *Project* 2061. In order for science education to be achieved for *all* Americans, *Project* 2061 staff have commited to ensure that the final products address the issue of equity "fully, fairly, and with insight."

- Model curriculum design, though it is guided by *SFAA*, primarily is in the hands of teachers, in contrast to other efforts where university professors or private curriculum developers have taken the lead. The assumption of the developers is that this approach increases the likelihood that the models will be considered valid and be adopted by teachers and school administrators in the future.

- The teachers are being asked to develop model curricula, which differs from the more common teacher activity of generating variations of existing curricula. Thus, the model curricula are driven by the learning goals developed in Phase I; the development process does not start with the current curriculum; it is subtractive rather that additive with respect to content; it does not rely on current textbooks; it stresses the interrelatedness of science, mathematics and technology; it attempts to map out learning across all 12 grades; and it does not assume the status quo of the present school system.

- The project is intended to address the needs of the whole educational system. This includes goals, curriculum, assessment, teacher preparation, policy, and instructional organization, all of which must be mutually supportive for science education reform to succeed.

GOALS

The ultimate goal of *Project* 2061 is that science literacy be achieved for all Americans. According to the authors of *SFAA*, there are no valid reasons why the schools in the United States cannot provide an educational system that makes it possible for all students to achieve this goal. What is required is a coordinated, cooperative effort with national commitment.

The council responsible for Phase I and the *SFAA* report set forth a number of science learning goals for all American children. They include understanding the following:

- the scientific endeavor, that is, the nature of science, mathematics, and technology as human enterprises;
- basic knowledge of the world from the viewpoint of science and mathematics and shaped by technology;
- some of the great episodes in the history of the scientific endeavor.
- crosscutting themes (systems, models, constancy, patterns of change, evolution, and scale) that have been shown to be useful in thinking about how things work; and
- "habits of mind" (i.e., possessing certain scientific values, attitudes, and patterns of thought) that are necessary for scientific literacy.

CONTEXT

Project 2061 was developed in a context of widespread belief that the citizenry of the United States was scientifically illiterate. Science educators point to a number of problems regarding teacher preparation and the science textbooks currently in use. For example, teachers are seen as not adequately prepared to teach science and mathematics. Adequate changes have not been made by the teaching profession, licensing bodies, and the schools to improve teacher preparation. Teachers have heavy teaching loads, which precludes their ability to perform well, even when they are well prepared. The textbooks in current use have a number of flaws: they do not emphasize the interrelatedness of the sciences, do not encourage cooperative learning, and stress memorization of facts rather than the understanding of concepts.

This lack in preparedness in science and mathematics among students is not only a reflection of inadequate teacher preparation and textbooks. It is a systemic problem, affected by every aspect of education. *Project* 2061 is offering a vision, curricula, and blueprints for change as a structure for addressing the various factors that must work together to make scientific literacy a reality: teacher education, materials and technology, equity of education among all students with attention on underrepresented minorities, school policy and organization, the role of parents and community as well as that of business and industry, and assessment of student learning.

PROCESS, CONTENT AND OUTCOMES

Phase I -- 1985 to 1989

Phase I was preceded by a three year planning process. In 1985, the National Council on Science and Technology was appointed by the AAAS board of directors and was asked to answer the question: Out of the myriad of possibilities, what should all high school graduates understand about science, mathematics and technology? To assist the council with this task, five 8-10 member scientific panels were charged by

AAAS to develop independent reports. The following areas were addressed: Biological and Health Sciences (Clark, 1989); Mathematics (Blackwell and Henkin, 1989); Physical and Information Sciences and Engineering (Bugliarello, 1989); Social and Behavioral Sciences (Appley and Maher, 1989); and Technology (Johnson, 1989). The panels met often over a two year period to develop the reports. The council and *Project* 2061 staff drew from these reports to prepare *SFAA*, a process that took more than three years.

"The National Council was asked to answer this question: **Out of all the possibilities, what knowledge, skills, and habits of mind associated with science, mathematics, and technology should all Americans have by the time they leave school?**" (*SFAA*, p. 19.) Council members deliberated on this question with' ı the following constraints (*SFAA*, p. 19):

- Nothing should be automatically included in the recommendations, no matter how long it may have been imbedded in curricula, textbooks, and exams;

- consider possibilities across all of science, mathematics, and technology, but do not strive necessarily for equal portions of each;

- establish learning goals that are modest enough to make sense for all students (including those who do not ordinarily perform well academically) but that are nevertheless ambitious enough to raise the sights of students and teachers; and

- adhere to the "less is more" principle -- an emphasis on learning relations among key concepts rather than numerous facts.

The *SFAA* recommendations are designed to be of scientific and human significance as suggested by the following criteria (*SFAA*, p. 21):

Utility. Will the knowledge or skills significantly enhance the graduate's long-term employment prospects, or be useful in making personal decisions?

Social Responsibility. Are the recommendations likely to help citizens participate intelligently in making social and political decisions on matters involving science and technology?

Intrinsic Value. Does the proposed content present aspects of science, mathematics, and technology that are so important in human history or so pervasive in our culture that a general education would be incomplete without them?

Philosophical Value. Does the proposed content contribute to the ability of people to ponder the enduring questions of human meaning such as life and death, perception and reality, the individual good versus the collective welfare?

Childhood Enrichment. Will the proposed content enhance childhood?

The range of recommendations produced by *Project* 2061 staff and the National Council in response to the above guidelines can be understood partially by inspecting Table 1, an abridged table of contents from *Science for All Americans*. The recommendations reflect a broad definition of scientific literacy that includes technology, mathematics, and social science as well as the life, physical, and earth sciences. A number of topics included in the recommendations seldom are treated in today's science curricula: the scientific enterprise and "habits of mind" (Chapters 1, 12); the nature of technology and the designed world (Chapters 3, 8); and themes (Chapter 11). The advocacy of broad themes for organizing science content within and across scientific disciplines has been taken up by the science education community: *SFAA*'s recommendation for themes often is cited in documents prescribing science education reform and many states are using themes in their science curriculum frameworks. For example, California worked with *Project* 2061 to ensure that its state science framework positions the science curricula toward the time when *Project* 2061 is ready to be implemented. Moreover, the California framework incorporated many of *SFAA*'s goals and is written in a narrative prose similar to *SFAA* (illustrated below).

The paragraph below, taken from the "Cells" section of Chapter 5, illustrates the form and level of detail for *SFAA*'s recommendations:

All self-replicating life forms are composed of cells -- from single-celled bacteria to elephants, with their trillions of cells. Although a few giant cells, such as hen's eggs, can be seen with the naked eye, most cells are microscopic. It is at the cell level that many of the basic functions of organisms are carried out: protein synthesis, extractions of energy from nutrients, replication, and so forth. The mechanisms by which these processes occur are similar in all living organisms. In addition, most cells perform certain specialized functions. (p. 61)

Five additional paragraphs are devoted to cells. Each of *SFAA*'s 170 pages of recommendations is written in narrative prose.

SFAA recommends what students should learn by the time they complete high school. The text of *SFAA* is meant to "express the residual knowledge, insights, and skills that people should possess after the details have faded from memory. If high school graduates were interviewed about a topic they should be able to come up, in their own words, with the ideas sketched in the paragraphs." (p. 22)

Some recommendations in *SFAA* have generated controversy, particularly the extensive recommendations for human and social science: mental health (Chapter 6) and human society (Chapter 7). Scientists who believe science curricula should be restricted to traditional content from the natural sciences criticize the inclusion of social science. Conservative segments of the public believe that some of *SFAA*'s social science recommendations are outside the purview of public schools.

Science for All Americans is not meant to be a curriculum or a textbook and does not contain any objectives. It does not specify what should be taught in any particular course or at any grade level; such information will be an outcome from Phase II of *Project* 2061.

Outcomes of Phase I

According to the developers, *Project* 2061 already has contributed greatly to the educational reform movement. The products of Phase I -- *SFAA* and the five panel reports -- have (a) assisted the scientific community in thinking about precollege education; and (b) provided conceptual frameworks for reform efforts by school districts, states, and individual teachers.

Initially, 2 300 sets of Phase I reports (a set consists of *SFAA* and the five Panel reports) and 5 000 copies of *SFAA* were sent to key legislators, officers and executives of scientific and educational organizations, and the media. Subsequently, over 20 000 copies of *SFAA* were purchased by teachers, university faculty, and librarians. A second edition of *SFAA* (priced at $9.95) was published by Oxford

Table 1

Abridged Table of Contents from *Science for All Americans*

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1. **The Nature of Science**

   The Scientific World View; Scientific Inquiry; The Scientific Enterprise

2. **The Nature of Mathematics**

   Some Features of Mathematics; Mathematical Processes

3. **The Nature of Technology**

   Science and Technology; Principles of Technology; Technology and Society

4. **The Physical Setting**

   The Universe; The Earth; Forces That Shape the Earth; The Structure of Matter; Transformations of Energy; The Motion of Things; The Forces of Nature

5. **The Living Environment**

   Diversity of Life; Heredity; Cells; Interdependence of Life; Flow of Matter and Energy; Evolution of Life

6. **The Human Organism**

   Human Identity; Life Cycle; Basic Functions; Learning; Physical Health; Mental Health

7. **Human Society**

   Cultural Effects on Behavior; Group Organization and Behavior; Social Change; Social Trade-Offs; Forms of Political and Economic Organization; Social Conflict; Worldwide Social Systems

8. **The Designed World**

   The Human Presence; Agriculture; Materials; Manufacturing; Energy Sources; Energy Use; Communication; Information Processing; Health Technology

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Table 1 Cont'd

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9. The Mathematical World

Numbers; Symbolic Relationships; Shapes; Uncertainty; Summarizing Data; Sampling; Reasoning

10. Historical Perspectives

Displacing the Earth From the Center of the Universe;
Uniting Matter and Energy, Time, and Space;
Uniting the Heavens and Earth; Extending Time; Understanding Fire; Splitting the Atom; Setting the Earth's Surface in Motion; Explaining the Diversity of Life; Discovering Germs; Harnessing Power

11. Common Themes

Systems; Models; Constancy; Patterns of Change; Evolution; Scale

12. Habits of Mind

Values and Attitudes; Skills

13. Effective Learning and Teaching

Principles of Learning; Teaching Science, Mathematics, and Technology

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University Press in December, 1990, as a trade paperback for national distribution. *SFAA* has since undergone another printing. In addition, a limited number of copies (750) were printed in clothcover. Distributions are:

> **Paperback.** Approximately 35 000 of the 45 000 copies printed have been sold to the following: (a) **IBM** purchased 22 000 copies for a special sale; (b) **bookstores** (Waldenbooks and B. Dalton) and **wholesalers** (Ingram and Baker and Taylor) sold approximately 6 000 copies; (c) Oxford University Press launched a mail campaign targeting **university professors** and 2 000 copies of SFAA were purchased for use in courses; and (d) primarily through combined efforts with AAAS, approximately 2 000 copies have been sold to **individuals** partly by including an order form in brochures distributed at teachers' conventions.
>
> **Clothcover.** Approximately 450 clothcover copies of *SFAA* have been sold, mostly to libraries.

A systematic survey on how individuals and groups are using or plan to use *SFAA* in their reform efforts has not been conducted. However, a request was made in the first publication of *Project* 2061's newsletter, *2061 Today* (Spring, 1991) for such feedback. Responses came from classroom teachers, department chairs, curriculum writers, curriculum committees, administrators, university professors, and museum directors. Some examples of how *SFAA* is being used are: as a guide in lesson planning, setting department goals, updating views on curriculum, teacher training, and exhibit development.

Project 2061 staff conduct numerous outreach activities. They state that they receive an overwhelming number of requests, far more than can be accommodated with current staffing. Outreach formats include workshops, panel discussions, and talks at major conferences of science teachers, mathematics teachers, and technology education teachers. Presentations have been made to such organizations as the National Science Teachers Association (NSTA), the Association for Supervision and Curriculum Development, and the International Technology Education Association. The staff has not developed a formal tracking mechanism to determine what the various recipients do with the information given at briefings.

Phase II -- 1989 to Present

In Phase II, the intellectual framework established in Phase I is to be converted into educational guidelines for reform. This phase, which began in 1989, consists of four major components:

- The design of six alternative **curriculum models** from kindergarten through twelfth grade, each capable of producing the outcomes enunciated in *SFAA*.
- The specification of 11 **blueprints** for action -- recommendations for needed reforms in the educational system that support the implementation of the model curricula;
- The development of a consensus document entitled **Benchmarks** that identifies what children should know at selected checkpoints (for example, at grades 2, 5, 8, and 12). Also to be included in this report are sample indicators of progress; and
- The dissemination of information and the formation of linkages with education associations and major reform efforts.

Curriculum Models

The central activity of Phase II is the development of alternative curriculum models. To accomplish this task, AAAS established six 25 member teams. Each team consists of 5 elementary school teachers, 5 middle school teachers, 10 high school teachers, 3 principals from elementary, middle, and high school, and 2 curriculum specialists. Teachers of science, mathematics, social studies, and technology are represented in each team. In addition, individuals selected for each team were to reflect the gender and race composition of the district teaching staff, have a positive teaching history, and believe that all children could achieve the learning goals in *SFAA*.

A number of criteria guided selection of sites for curriculum development: (a) Collectively, the sites had to represent the diversity of school districts in the nation; (b) at each site, school officials had to be willing to give team teachers considerable released time -- 40 days during the school year for each of two years, plus two summers; (c) state and school districts had to be willing to provide funding for the project as well as time; (d) states had to commit to review their own curriculum guidelines; and (e) there had to be a local university in close proximity to provide intellectual resources.

The following sites fulfilled the necessary criteria:

Georgia	consortium of three rural school districts near Athens
McFarland, Wisconsin	three schools, essentially a suburb of Madison

Philadelphia	a large inner-city school serving primarily African American students
San Antonio	four school districts serving primarily Hispanic students
San Diego	multicultural, suburban school district
San Francisco	multicultural school district, inner-city in character

Teams worked on their models at specified work centers. The locations of the work centers varied: two were located at universities; three at separate facilities; and one was located at a high school. The teams had funding for reference materials, consultants, and travel. Also, a telecommunications system linked team members with each other, other data bases, and project headquarters in Washington, D.C. The teams received intensive training during the summers of 1989 and 1990. For example, at the 1989 four-week summer institute, team members heard presentations on a wide array of topics in science, mathematics, and technology. Each week of presentations was organized around a theme: Microscopic Explanations of Macroscopic Phenomena; Evolution as a Unifying Theme in Biology; Risk and Probability; and Interaction of Science, Mathematics, and Technology.

The curriculum models being developed are to be interpretations of the premises, content, organization, and approach of a K-12 curriculum likely to produce the learning outcomes defined by *SFAA*. That is, since *SFAA* specified broad learning outcomes at the completion of K-12, teams were to determine what learning experiences during K-12 would produce them, a development process that project members termed "backmapping."

Below are four aspects of the AAAS plan for designing the models:

- Team members were to maintain their regular teaching or administrative duties while they developed their models. The rationale for this schedule was that the team members would develop a deeper understanding of *SFAA* over time and keep the needs of the students in mind.

- In developing models, teams were to disregard current constraints of the school system and specify what changes would facilitate implementation of their curriculum models.

- The models were to be conceptually complete but not to contain details necessary for implementation; for example, they would not contain teaching materials nor daily class schedules, rather, the adopting schools would have to "finish" them. The developers believe that this need to supply specifics will motivate schools to take ownership of the curricula during Phase III of *Project 2061* and have some investment in their successful implementation.

- Since team members had access to students during the development process, they could ask children what they understood about a particular topic, for example, in establishing benchmarks. However, *Project* staff discouraged teams from "trying out" their models in the classroom. Such try-outs were considered too time-consuming; also, schools might not be ready to support the new types of teaching required by the models.

Description of Models

After two years of work, the six teams submitted their draft model curricula to the central AAAS project staff in July, 1991: although these documents are listed in the references section at the close of the paper, AAAS is not ready to make them generally available since they are draft models that are undergoing considerable change. This section of the paper is intended to give readers a sense of how the model curricula differ from today's science curricula. Providing an exhaustive description or analysis of the models is beyond the scope of the paper, however, because the teams' models total approximately 1200 pages, ranging from 175 to 318 pages each. Every model has many aspects that move science curricula beyond today's standard fare, and, if space permitted, the novel aspects of every model could be illustrated. The following text briefly describes six features intended to be present in each model.

Philosophical Statements. Discussion of the nature of knowledge, childrens' learning, and the science curriculum.

For example, models emphasize the philosophy of *SFAA* that all children, including those in groups traditionally underrepresented in science, have the ability to learn science and should have access to learning experiences for science.

Focus of study. Description of the major themes, issues and problems, phenomena, concepts, or combination of these, around which the content is to be organized. Below are examples of organizing themes used by Project 2061 teams.

Georgia

Communication
Diversity and Interdependence
Energy
Environment and the Human Presence
Evolution
Forces
Human Society and Me
Matter
Part/Whole
Scale
Waves and Vibration
Weather and Atmosphere

McFarland

Food
Water
Energy
Communication
Transportation
Shelter and Architecture
Reproduction
Exploration
Living Organisms
Earth and Sky
Machines and Tools
Play and Recreation

San Antonio

Information Processing and Communications
Materials and Manufacturing
Human Presence
Health Technology
Energy Sources and Use
Agriculture

San Francisco

Elementary Years

Self
Communities
Biome
Universe

Middle Years

Gold Rush
Earthquakes

High School Years

Space Exploration
Water Use in the Bay Area
World Population
Mathematics Learning Experiences

The themes, issues, etc., of the Georgia, McFarland, and San Antonio teams are employed throughout K-12 while the San Francisco focus of study uses different themes during the elementary, middle, and high school years. The San Diego team organized its model around the chapters of *SFAA* listed in Table 1. The Philadelphia model discussed a number of themes as examples but does not present a definitive list of themes.

Content Inventory. The content that the students will encounter as they progress through the 12 grades, indicating the degree of sophistication expected at various levels. These are learning goals that fall within the major themes used to organize the focus of study. The amount of detail provided in this feature varies widely among the models.

The San Diego model, one of the most detailed, uses 70 tables each of which provides sample topics corresponding to a subchapter of *SFAA*. Further, the topics in each table are grouped into four grade ranges and categorized by *SFAA*'s six major themes (evolution, systems, etc.). To varying extents, all the models explicitly key their content inventory to the concepts in *SFAA*.

Instructional Form. The use of different modes of instruction (projects, seminars, investigations, case studies [historical or other], tutoring or mentoring, or traditional methods) at each grade level. Also, the degree of emphasis given at each level to individual instruction, cooperative learning, and large-group instruction.

These sections of the models most explicitly illustrate what the curriculum would look like in practice in the classroom. In several models, the classroom as it exists today is gone. In the San Antonio model, students attend different facilities for each of the six major themes, and these facilities are physically equipped and configured to support learning experiences in the themes. In the San Diego model, students alternately attend neighborhood resource centers and regional resource centers, with increasing amounts of time spent at the latter as they become older. Students in the last years of school would go to yet a third site for periods of time, the extended learning center, which would help them decide career directions.

Models provide differing amounts of detail when describing learning experiences and use different methods for describing them. The following excerpt from the San Antonio model, which uses fictional vignettes to illustrate future learning, relates the orientation of a student named Julio when he first arrives at the learning facility for the Energy theme (San Antonio Model, 1991, 3-4):

> *Julio noticed how the layout of the building complex was divided into specific areas dedicated to lab use, telecommunications, general meeting areas, and recreational facilities. Other areas seemed to be flexible, able to be adapted for a number of different purposes. Next, his slate displayed the time dimension as it showed him which areas of the building were in use at different times of the day.*
>
> *Another query gave background information on staff, community mentors, members of the local BIO (Business-Industry Outreach) and other students. He recognized the names of several of his former classmates. He also looked appreciatively at the cluster's list of completed projects that had been successfully integrated into both this and other cluster's curricula.*
>
> *Mentor Lee (the teacher) loaded Julio's disk into her desktop unit and studied the holograph which displayed his mastery of different areas of the curriculum through a series of peaks and valleys resembling a topographic map, showing areas of strength and areas not yet mastered. She noted that he had extremely high indexes in core Habits of Mind and social skills. She*

reviewed the computer's recommended list of activities and projects that would match the Cluster's resources and personnel to Julio's profile and preferences.

"With your interest in applications for solar power, you should be a big help there. We need your help in providing Spanish language instruction for our "teener" group; I've listed you as a peer tutor there. I've noticed you need a little work in spatial geometry so I scheduled you in for some lectures and structured group with Mentor Lewis. I'm especially glad that you have done so well in the social sciences, we really are in need of a good archivist for your cohort's experiences."

Co-requisites. Recommendations about reforms within the educational infrastructure that will be necessary for the new curricula to work. The co-requisites will be conveyed to the blueprint teams.

Some models are more futurist than others, i.e., the extent to which they disregard aspects of the status quo. The Philadelphia model portrays school organizations similar to today's schools: elementary, middle, and high schools; and secondary course offerings similar to the current ones.

Other models advocate curricula that necessitate fundamental reorganization of schools and school systems. Some of the features discussed above obviously had implications for different school organization. As another example, the McFarland model requires major school reorganization: (a) Groups of approximately 12 students ("clusters") stay with the same teacher for several years; (b) clusters contain students in the following approximate age ranges: 5-8, 7-11, 10-14, 12-16, and 14-18; (c) five clusters form a "house" of approximately 60 students, and five houses form a "community" (the whole school) which should never exceed 300 students (if a school must be larger, more than one community should be formed within it); (d) the curriculum is wholly interdisciplinary -- science content is used to incorporate all subject matter, thus traditional course structures are no longer required (in any subject).

Assessment. Designed assessments should measure depth of learning, not breadth. They must go beyond simple measuring of minimal knowledge; instead, they must be able to demonstrate that the students have attained conceptual understanding, can construct new knowledge, and can solve real-life problems. Assessment often is intended to blend with instructional strategies, and, ideally, the two are nearly indistinguishable. Each model recommends several assessment strategies, and collectively, a wide variety of strategies are suggested. Examples are performance tasks (e.g., demonstrations, designing or executing an experiment, etc.), portfolios (collecting of student's or student's work), cooperative performances (e.g., evaluating students' performance based on group cooperation), concept mapping (creating diagrams which illustrate connections between related concepts), multiple choice tests in which students must justify their choices in writing, self-assessment, interviews with students, anecdotal observations and observation checklists, journals and logs, and open-ended questioning.

Current Status

An augmented editorial board was formed in late summer 1991, consisting of four central *Project* 2061 staff, five members from each team, and five specialists (curriculum, science curriculum, technology curriculum, mathematics curriculum, and social studies curriculum). The board is charged with working out details of format, editorial policy, and internal and external review processes. It will study submissions, decide on the final number of models, and define the plans for the work yet to be done.

At its first meeting in July 1991, the board reviewed the models and provided feedback to the teams for refining their work. Each team is to try applying one of four approaches to their respective model as they refine it. These approaches reflect various techniques to teach the material, and they were provided by the central AAAS staff: **design** (how we use what we know); **inquiry** (how we know); **knowledge** (what we know); and **perspective** (why it is important for us to know, i.e., how science knowledge and applications influence society). Early feedback from the teams is that a good curriculum may require the combined use of two or more of the four approaches.

The central AAAS staff and National Council mandate that teams revise their models to incorporate one or more of the four approaches caused considerable tension between central AAAS staff and the teams. It is unclear how much teams will have to change their models to reflect the approaches. The teams have had considerable autonomy, perhaps increasingly so, in developing their models. While the central AAAS staff are the architects and general contractors for the development process, they have served more so as catalysts, advisors, coordinators, supporters, and an intellectual resource. Hence, teams have perceived the forced introduction of the approaches as a change in the playing field. The central staff, having ultimate responsibility for and authority over the project, constantly work to strike a balance between empowering the teams and guiding them.

The dynamic between the central AAAS staff and the teacher development teams is a unique feature of *Project* 2061. The more common strategy during the recent history of federally-sponsored curriculum development projects has been for scientists, science educators, and classroom teachers to develop curricula collaboratively during the same period of time, often with scientists as the project leaders. In contrast, *Project* 2061 commissioned scientists to prescribe the scientific goals of the curriculum in Phase I, and subsequently established teams of classroom teachers to be the primary developers of the model curricula during Phase II. Although scientists and science educators have been involved as consultants, it is teachers who have primary responsibility for developing the models.

The editorial board will meet again in winter 1991 to choose a set of models for further refinement and to define a work plan. The final drafts of the model curricula will be reviewed in the latter part of 1992 by a wide array of individuals: teachers, school administrators, education policy makers, engineers, mathematicians, natural and social scientists, historians, representatives of business and labor, the blueprint authors, and Phase I panelists. After appropriate revisions, the models are scheduled to be published in 1993.

Benchmarks

A task that arose from the curriculum development process is to produce a consensus document entitled *Benchmarks*. It is being developed by the team members with input from other educators. This document will be included in the major report for Phase II, *Designs for Change*. *Benchmarks* is to consist of statements of what students should learn at selected checkpoints (for example, at grades 2, 5, 8, and 12) as they make progress towards the twelfth-grade goals of *SFAA*. This endeavor is in keeping with the current drive towards establishing educational standards in the core subjects, following the example set by the National Council of Teachers of Mathematics (NCTM) with its publication of *Curriculum and Evaluation Standards for School Mathematics*. *Benchmarks* also will include sample indicators of progress. The *Project* 2061 developers believe that both *SFAA* and *Benchmarks* will contribute to the National Research Council project to establish national standards for science education.

Blueprints for Action

The blueprints envisaged by the *Project* 2061 developers are to be reports that will contain recommendations for change in the educational infrastructure to facilitate the implementation of the model curricula. AAAS staff consider these blueprints to be essential for the success of *Project* 2061.

Originally, four blueprints were to be prepared in parallel with the curriculum models. As development of the models proceeded, however, it became apparent that the curriculum teams needed to be well along before work on the blueprints could begin. Hence the *2061* staff decided to invest available resources in the curriculum models and defer work on the blueprints. In the meantime, they identified additional topics for blueprints, increasing the number to eleven. The role of the blueprints remains unchanged: to provide support for the curriculum models; their development is to be guided by the recommendations made by the model teams.

Development of the blueprints is under the direction of a central *2061* staff person. Writers will be linked by a telecommunications system that will allow them to share information with each other and with the model teams as they continue to refine their models. To get started, the blueprint writers met with the expanded editorial board in summer 1991 and reviewed the curriculum models. So far, authors have been selected for nine of the 11 blueprint topics. The topics to be covered in the blueprints are:

Equity. Described by the developers as "at the heart of the *Project*," since the fundamental premise of *2061* is that science literacy can be attained by *all*. The authors for this topic are to ensure that all products of *2061* address the issue of equity fully. Chief writer: Cora Marrett, Professor of Sociology, University of Wisconsin/Madison.

Teacher education. Recommendations for the initial and continuing education of teachers, based on the goals and curriculum models of *Project* 2061. A subtopic will address the need to develop a set of learning materials to supplement *SFAA* in training teachers to be fully literate in science, mathematics, and technology. Chief writer: Mary Kennedy, Director, the National Center for Research on Teacher Learning, Michigan State University.

Assessment. Viewed as a critical component of curriculum, since results are used to judge both curriculum and instruction and students. In this blueprint, the assessment requirements of each of the models are to be considered. Since standard science tests may not be appropriate in the model curricula for assessment either of the students or of the program, less traditional approaches such as portfolios, project work, and performance tasks may have to be taken. The impact of these approaches will need to be considered in the context of each model. Assessment approaches are to be examined over the full range of the educational system - the classroom, the school district, nationally, and internationally. Chief writer: Wayne Welch, Professor of Evaluation Methods, University of Minnesota. In addition to the assessment blueprint, *Project* 2061 staff are working with the states of Michigan, Illinois, and California on a project to develop assessment resources related to *Project* 2061.

Materials and Technology. Instructional materials and hardware that will enable the teaching of the model curricula. Specifically, the usefulness of current developments is to be evaluated. Chief writer: Alan Hofmeister, Director, Division of Technology, Utah State University.

Curriculum Connection. Guidance on how to bridge the core *Project* 2061 curriculum in science, mathematics, and technology with other subject areas, particularly the arts and humanities. Chief writer: Graham Down, Director, Council for Basic Education.

School Organization. Alternatives for organizing schools so as to facilitate implementation of the models. In addition, school culture is to be examined in relation to the models. Chief writer: Robert Donmoyer, Professor of Educational Policy and Leadership, National Center for Teaching and Learning Science, Ohio State University.

Higher Education. Changes that will have to occur in admissions policies in colleges and universities in order to accommodate the *Project* 2061 reforms. The authors are to examine such relevant issues and recommend changes. Chief writer: Carol Stoel, College/School Programs, American Association for Higher Education.

Business and Industry. The role of business and industry in this educational reform initiative. Chief writer: J. Myron Atkin, Professor of Education, Stanford University.

Policy. Modifications in policy which must be made for the curriculum models to work, including policies that govern school organization, teacher training and credentialing, high school graduation requirements, and scheduling and related uses of time. Chief writer: Susan Fuhrman, Director, Consortium for Policy Research in Education, Rutgers University.

The following topics are to be added:

Research on how children think and learn. Because such research is sparse, teachers often rely on intuition to develop curriculum. Therefore, authors of this blueprint are to examine the current body of research on learning science as it pertains to the models. In addition, new research directions are to be identified.

Roles of Parents and the Community. Many of the model curricula include community and family participation in the curriculum activities.

The blueprint writers started work in fall 1991; drafts are to be reviewed in early 1992. After revision and refinement, the blueprints are to be published in 1993.

Dissemination of Information and Linkage Strategies

A number of dissemination efforts and linkages with education associations and major reform efforts have been initiated or are being planned:

- A newsletter entitled *2061 TODAY* has been distributed quarterly since spring of 1991. Funding has come from AAAS and government support for *Project 2061*.

- The project plans to build a large pool of implementation leaders, starting with the 150 team teachers involved with developing the model curricula. This effort eventually may involve teacher training workshops.

- When the curriculum development teams met in summer 1991, they also were asked to develop strategies for curriculum adoption and implementation in their respective school districts. At the onset of Phase II, each state that "housed" a curriculum team agreed to consider state adoption of the curriculum upon completion. This was not, however, the agreement at the local level among the superintendents. The status of adoption and implementation negotiations with the local school superintendents varies among the teams. One team already is working with other teachers in the school district to prepare for implementation of their model in summer 1992. Other teams are still developing plans. The 2061 staff is providing assistance in the following ways: funding; technical assistance, with visits to sites when appropriate; and identification and contacting of key players, e.g., state superintendents.

- A National Resource Base is being established through a telecommunications network. With this resource, a user will have access to support materials for the implementation of a chosen model. Information for this resource base will be supplied by the model curriculum development teams. This task is being partially funded by a three-year grant from the U.S. Department of Education's Dwight D. Eisenhower National Program for Mathematics and Science Education.

- A *Project* 2061 users network, which is to be a communications system that connects all current Phase II sites and any additional ones. This system is slated to be available for widespread use by late 1995.

- Affiliates of *Project 2061* are to be established, to accommodate states and school districts expressing the intention to implement the recommendations of *SFAA* before curriculum models and blueprints become available. Affiliates will be connected through a computer network. The first affiliate is the New York City school system. It has pledged to use *SFAA* as a guide to initiate curriculum change, to assist *Project* 2061 in the development of strategies to integrate technology into the K-12 curriculum at every level, and to select teachers and administrators to review draft recommendations made by the curriculum teams. Also, the need to reform science, mathematics, and technology education will be publicized in New York City through public relations activities and advertising. Other affiliates are the ten states awarded grants under the National Science Foundation's State Systemic Initiatives (SSI) Program and grantees of the Department of Education's Eisenhower Program. Collaborative activities will vary; for example, AAAS will share information such as the draft *Benchmarks* with the states involved in the SSI programs. More affiliates are to be added as Phase II proceeds.

- A number of vanguard districts and states are to be nominated that will collaborate with AAAS in an effort at full fledged reform of science education. They will include the Phase II sites and some of the affiliates.

- *Project* 2061 has linked with a number of education associations and such other major education reform activities as The National Science Teachers Association's Scope, Sequence, and Coordination (SS&C) project, The Mathematical Sciences Education Board (MSEB) of the National Research Council, The International Technology Education Association (ITEA), the National Commission on Social Studies in the Schools, the State Systemic Initiative through the National Science Foundation, and the Department of Education. Further linkages are planned.

- A major marketing effort is planned for the Phase II reports so that they will heighten awareness and discussion among educators and the public about the reforms needed in science education.

- An annual status report is to be prepared on the *Project*'s efforts to reform science, mathematics, and technology education and accomplishments during each year. It is to be distributed nationally.

- AAAS is interested in conducting a national assessment of science literacy of 17 year-olds to serve as a baseline against which to measure the impact of the reform movement over time. This effort is presently on hold but remains of interest to *Project* 2061 staff.

PHASE III

Planned to take ten or more years, Phase III is envisaged as a broad-based campaign to foster the use of the alternative curricula and related materials for science, mathematics, and technology education across the United States. Some activities initiated in Phase II will continue into Phase III. They include the newsletter and the national resource base. Also planned is the publication of an action handbook and special-audience papers. The action handbook is to be a resource book to help school districts implement reforms based on the models and blueprints. The first edition of the handbook is planned to be published in 1993-1994 and a revised edition is planned for 1994-1995. The special audience papers are to be brief monographs, aimed at particular audiences who must establish policies or conduct science education reform, that summarize the main implications of the Phase I and Phase II reports. They are expected to be published in late 1993. *Project 2061* staff view these transitional activities as effective mechanisms to progress from design to preparation to implementation.

Science reform requires the sustained, coordinated efforts of individuals, institutions, and organizations. It must involve administrators, university faculty members, community and political leaders, teachers, parents, and students. Thus a major charge for *Project 2061* in Phase III is to keep scientific literacy and educational reform on the agenda of educators, scientists, policymakers, and the public.

QUESTIONS FOR A SET OF CASE STUDIES

Project 2061 has captured a great deal of attention with its distinctive long-range strategy for reforming science education. The two-phased strategy of having scientists establish the framework for the reform and then having educators translate the framework into curriculum models and blueprints for action represents a particular set of assumptions about the nature of science, education, and the schools. Whether these assumptions will lead to effective reform will not be known until the curriculum models are widely available and implemented by schools. The following are possible questions to consider for studying *Project* 2061 in the next few years.

Models and Initial Sites

1. What were the detailed specifics of the model development process? For example, to what extent and in what ways were science and science educators consultants involved? How have administrators supported the teams' work?

2. How do AAAS central staff and the project teams perceive their own roles and each others' roles?

3. In what ways and to what extent will teams revise their models in response to the four recommended approaches (design, inquiry, technology, perspective)?

4. How will the implementation process begin? Will versions of the models be created for the beginning of Phase III that require less structural reorganization of schools and school systems? To what extent are the districts that supported the teams' development work willing to implement the models?

5. What are the concerns of school superintendents and building administrators regarding model implementation, particularly with respect to administrative problems that may be raised by each

model? For example, how will student placement be changed from single grades to clustering by age groups, as required by several of the models?

6. How will schools deal with the problem of articulation with institutions of higher education that may not accept the validity of the new curricula without traditional indicators of achievement and ability?

Benchmarks

7. Do scientists, teachers, and science educators appraise the "Benchmarks" to be appropriate achievement targets for the given grade levels in the future?

8. In what ways will the "Benchmarks" be part of the process for setting standards in science education?

Feedback/Evaluation

9. *Project* 2061 staff have stated that effectiveness of the *Project 2061* materials in the field must be evaluated. How will these evaluations be designed and carried out?

Interest and Enthusiasm for the Reform

10. Will states, school systems, scientists, teachers, science educators, and policy makers have increasing enthusiasm and confidence in this reform initiative once the results of Phase II become generally available?

11. How are organizations and individuals that are not officially associated with *Project 2061* using *Science For All Americans* in their programs?

REFERENCES

All source documents for this paper were authored by *Project 2061*, American Association for the Advancement of Science, Washington, D.C.:

Science for all Americans. 1989.

Science for All Americans. Summary. 1989.

Project 2061: Education for a Changing Future. The transition from Phase II to Phase III: A Prospectus. December 1990.

2061 TODAY. Spring 1991 1(1):1-6.

2061 TODAY. Summer 1991 1(2):1-6.

2061 TODAY. Fall 1991 1(3):1-6.

The following publications were produced by panels of scientists during Phase I of *Project* 2061; they served as the basis for the final Phase I report, *Science for All Americans*:

Clark, M., *Biological and Health Sciences.* 1989.

Blackwell, D., & Henkin, L., *Mathematics.* 1989.

Bugliarello, G., *Physical and Information Sciences and Engineering.* 1989

Appley, M., & Maher, W., *Social and Behavioral Sciences.* 1989.

Johnson, J., *Technology.* 1989.

The following are draft curriculum models produced by the curriculum development teams during Phase II of *Project* 2061:

Texas Technology Model. Draft. June 20, 1991.

Project 2061. Educating for a Changing Future. McFarland Model. Draft. July 1991.

Project 2061. Georgia Team Curriculum Model. Draft July 1991.

Philadelphia Team. Science For All Americans. Curriculum Model. Draft. June, 1991.

AAAS Project 2061. San Diego Team. Greater Learning Opportunities By Accessing Localities MODEL. An Educational Vision for the 21st Century. June, 1991.

San Francisco Project 2061 Curriculum Model. Working Document. June, 1991.

INNOVATIONS

IN

MATHEMATICS

EDUCATION

MATHEMATICS EDUCATION REFORM IN CALIFORNIA

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INTRODUCTION

Central to education in the United States are the educational systems in each of the 50 states. Each state has the responsibility for developing its own education system. Some states have a strong centralized system: The Department of Public Instruction in North Carolina specifies, for example, learner outcomes, administers end-of-course examinations, selects textbooks, evaluates teachers, and determines what teachers are paid. Other states such as Montana operate with a very small office of education and leave nearly all of the educational decisions to its local community school districts. Many states fall in between by exerting some state control while deferring a large number of decisions to the local level. California is one of these states. Even though California's education system is similar to that of a number of other states, its systemic approach to education reform in the decade of the 1980s has received great deal of attention from the other states and serves as a model to follow. This case study focuses on only one part of California's reform efforts, what has been done to make changes in mathematics education. To understand these reform efforts, it is helpful to have some knowledge of California's diverse population and geography; how California's education system works and where the authority for education resides; some of the history of curriculum recommendations in the recent past; and how a multiplicity of efforts in the state is being orchestrated to bring about change in mathematics education. The study of mathematics education reform in California reveals some of the basic constraints that are operable in, as well as the mechanisms available to, any state attempting to generate change. California represents a massive effort to further statewide reform in mathematics education while giving every student fair access to mathematics. California provides a rich case for study because of its attempts to align policy and practice.

A STATE OF DIVERSITY

California, known the world over for its vast treasures, conjures an image of fun, energy, movie stars, and Disneyland. The city of San Francisco covers the hills under the shadow of the Golden Gate Bridge. The Sequoia National Forest is studded with some of the tallest trees on earth. The General Sherman sequoia is 275 feet high and estimated to be 3,500 years old. Yosemite National Park's sheer cliffs tower over dramatic waterfalls. The rich San Joaquin Valley produces vegetables for consumption around the world. Most of the nation's processing tomatoes, nearly 90 percent, are grown in this and the adjacent Sacramento Valley. Lettuce, melons, cotton, sugar beets, wheat, barley, onions, garlic, prunes, olives, almonds, rice, watermelons, grapes, raisins, and broccoli all flourish in the state's nourishing soil. Hollywood's movie industry glamour radiates in millions of theaters. San Diego's large naval base harbors ships that travel to all parts of the world.

California's topography varies as much as its people. Its Pacific coastline meanders over 840 miles from the sandy beaches in the south to the rocky shores in the north. The 14,495-foot Mount Whitney, the highest point in the 48 contiguous states, is only 85 miles from Death Valley and the lowest point in the state 282 feet below sea level. Temperatures in Death Valley have exceeded 130 degrees Fahrenheit. Communities range from small villages such as Tom's Place, Coleville, and Sattley on the eastern slopes of the Sierra Nevadas to sprawling Los Angeles, the second largest city in the United States, with a 1990 population of over 3.4 million. Nearly one half of all of California's 29.7 million people live in Los Angeles County.

Geographically and economically, California can be divided into four areas. The Bay Area -- San Francisco, Oakland and San Jose -- supports a population of approximately 3 million living in both suburban and urban conditions. Silicon Valley stretching north of San Jose spawns high-technology companies. A key financial center for the Pacific Rim, San Francisco's increasing affluence pushes those with less income across the bay to Oakland. The second region is the San Joaquin Valley, residence for nearly one million. This fertile valley provides work for a large number of immigrant agriculture workers. The third region is comprised of the vast lands in the north and east -- over half of the land area in the state, supporting less than 10 per cent of the state's population. These regions include very depressed rural areas and only a few industries such as timber. The fourth and most populous region of the state, Southern California, stretches from the Tehachapi Mountains to the Mexican border and includes Los Angeles and San Diego counties. Over 23 million, nearly 80 per cent of the state's population, live in a range of conditions from urban slums to opulent enclaves. Some of the riches people in the United States live, or have residences, in California coastal communities such as Newport Beach, Santa Monica, and Pacific Palisades. Large immigrant populations from Southeast Asia, Central America, Mexico, and South America have moved to this freeway-entangled area. Los Angeles and its surrounding communities have thrived on expansion of the aero-space industry, including corporations such as Hughes Aircraft, Northrop, TRW, Lockheed, McDonnell Douglas, and Rockwell International. The area in the early 1990s was experiencing layoffs as the industry made adjustments due to the shifting economy.

CALIFORNIA'S EDUCATION SYSTEM

States in the United States have the responsibility for education by default. The Tenth Amendment of the Constitution specifies, "The powers not delegated to the United States by the Constitution, nor prohibited by it to the states, are reserved to the states respectively, or to the people." Since education is not mentioned in the Constitution, it becomes under this amendment the jurisdiction of each of the fifty states. Each state has its own education system, which generally includes a chief administrator, in many states a state board of education or department of education, possible regional education agencies, and community school districts each operated by its own school board and administrator. The legislature -- the elected representatives -- in each state pass laws that develop regulations for operating schools and allocate funds for financing schooling. Some states maintain strong control over schools while other states delegate greater authority to local districts.

The California State Department of Education

The major authority for education in California rests with the 1,012 local community school districts. The state allocates annually to each district a specified amount of funding per student, plus a supplement for some larger urban districts. Each district has the authority to specify its curriculum, teachers' salaries, the professional development of its teachers, and graduation requirements. A State Board of Education is appointed by the governor of California. This board provides some direction on policy issues, but does not have any real authority for guiding education in the state. The State Board of Education does give its cursory approval of the curriculum frameworks.

The California Superintendent of Public Instruction, elected every four years, is the chief educational administrator in the state. The power of the superintendent is limited to providing leadership and guidelines; carrying out state education legislation, and administering federal education and title programs. The current superintendent, William Honig, has served in this position since early 1983, when he assumed office following his election the November before. He heads the California State Department of Education housed in Sacramento. A superintendent for the state can develop some priorities. One priority established by Mr. Honig that has received a significant amount of attention is curriculum reform. Mr. Honig is viewed by staff members as a prolific and rapid reader with a vast memory. He stays current on trends and advanced thinking in education. At, for example, meetings on the state's assessment program recently, he was able to draw on information from the New Standards Project, the developments in the National Assessment of Educational Progress, and other current assessment programs. As head of the Department of Education he is progressive and takes a personal interest and role in planning reform. The emphasis he has placed on curriculum reform in California has made him a prime mover for general educational reform in the state over the past decade.

A deputy superintendent manages Curriculum and Instructional Leadership and oversees the director of the Curriculum, Instruction, and Assessment Division. The director of mathematics, Dr. Walter Denham, works within this division and supervises a group of three mathematics education consultants, all of whom promote, provide guidance, offer leadership, engage in strategic planning, and network for the improvement of the mathematics education curriculum program for the state. Dr. Denham has served as director of mathematics since 1983, six months after Mr. Honig assumed his duties. Unlike most mathematics officials for a state department of education, Dr. Denham's position is classified as a managerial one rather than as the traditional consultant or specialist position.

California's Student Population

The total student enrollment in California public schools in the 1991-92 school year reached 5 107 145 students. This is a 7 per cent increase over a period of three years. (Nearly 30 per cent of the students in California schools attend schools in Los Angeles County.) Public school student enrollment is constantly changing in composition. In 1967, 75 per cent of the student population was white, 14 per cent Hispanic, 8 per cent black, and 3 per cent Asian and other. In 1987 this had changed to 50 per cent white, 30 per cent Hispanic, 11 per cent Asian and other, and 9 per cent black. In 1991-92, for the first time, enrollment in any grade did not have a simple majority group. Overall, the enrollment included 44 per cent white, 35 per cent Hispanic, 11 per cent Asian/ Pacific Islanders/ Filipino, 9 per cent black, and 1 per cent Alaskan Native/American Indian.

There were 245 733 certified professional staff members in the public schools in 1988-89. Of these, 207 276 were full time equivalent teaching assignments, approximately 23 students for every teacher. The average age of a teacher was 43 and the average years of education service was 15. Over two-thirds, 68 per cent, were female, 81 per cent were white (not of Hispanic origin), 7 per cent Hispanic, 6 per cent were black (not of Hispanic origin), 3 per cent Asian, 1 per cent Filipino, and 1 per cent American Indian or Alaskan Native. Essentially all of the professional staff in California schools have at least a bachelor's degree and 41 per cent have a master's degree or Ph.D.

In 1989, 30.6 per cent of high school graduates in California completed the courses that are required for admission to the University of California system (U.S. History, four years of English, three years of mathematics, a laboratory science, and two years of foreign language), an increase from 25.4 per cent in 1985. The increase occurred across all major racial and ethnic groups. In 1989, the percentage of graduates satisfying the course requirements, by race and ethnicity, was 52.3 per cent Asian, 39.3 per cent Filipino, 31.8 white, 25.4 black, 24.4 Pacific Islander, 19.5 Hispanic, and 19.2 American Indian. The percentage of high school seniors in California scoring higher than 500 on the *Scholastic Aptitude Test*

(SAT) on a scale of 200-800 on the mathematics segment of the test increased from 16.5 per cent in 1985 to 20.5 per cent in 1989.

REFORM OF MATHEMATICS EDUCATION IN CALIFORNIA

Reform of mathematics education in California has gained momentum since the early 1980s. The driving force behind this momentum is the State Superintendent and his interest in curriculum change. Major reform mechanisms are in place and being used to institute change -- the mathematics curriculum framework, textbook adoptions, the California Assessment Program, California Mathematics Projects, and the Middle Grades Mathematics Renaissance. Before going into greater detail regarding these mechanisms, however, an overview of how they are interrelated and what role the state's Department of Education plays in sustaining them is described.

The California Department of Education does not have the authority to mandate to districts what mathematics will be taught to students or how it will be taught. The California legislature issues laws and mandates and the Commission on Teacher Credentials, independent of the Department of Education, establishes the requirements that have to be met to teach in the state and approves teacher education programs at state colleges and universities. Although the Department of Education's role in fostering change is limited to providing leadership, guidance, and support rather than offering a mandate, the Department has at its disposal certain mechanisms for effecting change in schools. All department changes in mathematics education are keyed to the mathematics frameworks. These documents define the vision for orchestrating changes in the mathematics curriculum. The framework establishes guidelines on what mathematics should be taught to students and how it is to be taught; it also serves as the basis for developing the assessment instruments. The first version of the *Mathematics Framework* was published in 1963 and has been revised every five-to-seven years as the first step in adopting each new round of K-8 textbooks. The cost for setting the curriculum criteria and evaluating material submitted for consideration is around $50 000. Overlap in people serving on the advisory committees for the different frameworks, and between the framework and assessment committees, ensures continuity and alignment both across time and across components. Up to 1988, one person had served as a member on all of the framework advisory committees since the first in 1963.

Mechanisms of Change and Control

The framework specifies the criteria to be used to select textbooks (K-8) and to guide any curriculum development process. For the past 30 years, since 1963, at the above-mentioned five-to- seven-year intervals, mathematics K-8 textbook series have been selected to be listed as approved by the Department for use in the state. The state annually issues each district $30 per student in Grades K-8, 70 per cent of which must be applied to the purchase of materials on the adoption list. Commercial textbook companies compete intensely in the effort to make the California list of approved texts and are highly influenced by the *Mathematics Frameworks.*

Since 1988, the Department of Education itself has engaged in the development of some curriculum materials, termed replacement units. These have been acquired and disseminated in different ways. To develop the first placement unit, an individual contractor was contracted by the Department to develop a unit. The second unit had already been written, so the Department only paid for that unit to be published and disseminated. The third unit was written and published and only required that the Department fund the training of teachers in its use. The fourth unit was developed by a project funded by the National Science Foundation. These units can be used by a teacher to replace large segments of the curriculum, such as a chapter in a textbook that may represent four-to-six weeks of instruction. These replacement units model instruction and content aligned with the 1985 *Mathematics Framework.*

Another mechanism used by the state to assure quality in education is the state assessment program. Each district is required annually to administer to its students tests prepared by the state. Since the early 1970s, a matrix sampling procedure has been used and results are reported by school and district, but not by individual students. In 1990, tests in reading, written expression, and mathematics were administered in Grades 3, 6, 8, and 12. Science and history-social science were assessed at Grade 8, and direct writing was assessed at Grades 8 and 12.

That same year the governor eliminated funds for the assessment program. The legislature reinstated the program that will begin testing in the spring of 1993 mathematics and language arts in grades 4, 8, and 10 and science and social studies in grades 5, 8, and 10. In 1991-92, tests in mathematics, language arts, science and social studies were only administered in grade 8.

The California Assessment Program (CAP) has been experimenting with alternative forms of assessment -- other than multiple-choice items -- in an effort to better align the assessment instruments with the curriculum frameworks and to apply greater pressure on districts to conform more to the *Mathematics Frameworks*. In 1992, approximately $10 million was allocated by the Department for operating the California Assessment Program including assessment development, administration, and scoring -- an amount that represented .05 per cent of the $20 billion spent on education in the state during the year.

A third mechanism for control and change is teacher certification and professional development. The state has the authority to specify the criteria for teaching in California public schools. Certification is issued for a variety of grade ranges including K-12, 9-12, K-6, and the middle grades. All certifications require a fifth year of study beyond the bachelor's degree. Those who graduate from California colleges and universities will normally get a bachelor's degree and then take a fifth year of education courses and student teaching prior to being certified. To be certified as a mathematics teacher for the middle grades requires 30 undergraduate credits in mathematics. Those certified to teach mathematics in Grades 9 through 12 must either major in mathematics or achieve a passing score on the mathematics test of the National Teachers Examination (NTE). All certified teachers must pass the California Basic Essential Skills Test (CBEST). Someone with a bachelor's degree can receive an emergency certification to teach providing he or she continues to take education courses and other required courses to fulfill the equivalent of the fifth-year requirement. The pace at which a person is required to achieve the necessary requirements is governed by the school district. California teachers since 1986 are required to be recertified every five years by obtaining a certain number of "seat" professional development credits, time spent sitting in a course without a requirement to pass the course. Beginning in 1989-90, all secondary teachers in a content area had to be certified to teach in that content area for a student to receive credit for the course. A person with a bachelor's degree without a mathematics major can meet this requirement by passing the NTE in mathematics.

Districts have the primary responsibility for providing professional development experiences for teachers. The state allows each school with school improvement funding, approximately 80 per cent of the state's schools, to allocate up to eight professional development days during a school year. In reality, districts generally use only three or four of these days. A school board may be faulted for permitting greater use than this of professional development days since it means that students are in class fewer days.

In 1983, the California legislature allocated funds for forming the California Mathematics Projects (CMP). The CMP created a structure to provide teachers with professional development experiences and generated a group of teachers that could provide leadership to other teachers. Two pilot projects, one at the University of California-Davis and one at the University of California-Berkeley, served as prototypes for developing other projects operating at institutions of higher education. Through these projects, three- to four-week summer institutes are conducted for teachers along with some follow-up activity during the school year. By 1992, 17 mathematics projects have been developed catering to K-12 mathematics teachers. The legislature allocated as part of the higher education budget in 1992 $1.5 million toward the cost of administering the program and toward partial funding of the regional projects.

A fourth mechanism for instituting change was initiated for the 1991-1992 school year. Called the Middle Grades Mathematics Renaissance, this program targets school-based change. Out of the 200 middle schools who were invited to apply, 78 schools applied and were included in the program. Seven teacher leaders, approximately 1 for each of 11 schools, were recruited to operate the program and to help teachers in these schools effect change. During the year two teachers from each of the schools will teach two of the replacement units. In the summer of 1992, 11 four-week summer academies were held in different locations around the state. At these academies the teachers actually taught students a replacement unit and then had time to discuss and analyze the experience. The Middle Grades Mathematics Renaissance is a major implementation strategy for effecting change in schools. Its relationship with the other change mechanisms is shown in Figure 1.

Mathematics Education Reform in Other States

California's efforts to reform mathematics education through the development of an integrated structure for change while having little authority to mandate change is different from most other states. California is the most populous of the 50 states and the sheer numbers of students, teachers, and schools, makes it different from the others. But California's integrated approach is revolutionary, inasmuch as it is intended: to provide a vision for what mathematics K-12 students should know and what teaching of mathematics should be like; to support this vision by giving teachers access to professional development experiences; to coordinate changes in the methods and outcomes for assessment; to provide for curriculum units; and to work toward school-based change that constitutes a comprehensive approach to reform.

Figure 1. Mechanisms for Mathematics Education Reform in California.

Middle Grades Mathematics Renaissance (School Based)		
↑	↑	↑
1992-93 Assessment Grades 4, 8, 10 (California Assessment Program)	Textbook Adoption and Replacement Units	Professional Development (California Mathematics Projects)
↑	↑	↑
Mathematics Framework		

Pennsylvania, one of the six most populous states, in 1992 took an outcome-based approach to reform. The Pennsylvania Board of Education adopted on March 12, 1992, a plan to tie students' graduation to their achievement rather than to their completion of a specified number of courses. Districts are to develop their own curricula, but these are to be aligned with the state goals. Students must demonstrate "mastery" of goals, called learning outcomes, in a range of subjects including mathematics before they can graduate.

Kentucky has adopted a related approach, but school districts can have their state funding cut if the district does not meet the state's standards, rather than tying the attainment of goals to student graduation. This action was initiated by a vote of the legislature in 1990 to establish the Kentucky Education Reform Act (KERA) and is to be phased-in over a five-year period (National Council on Measurement in Education, 1992). Assessment is a cornerstone of this reform and will have two components. One will be formative in nature, to help local educators monitor student learning. The other will be summative in nature, and will be used to issue rewards and sanctions. Formative tests will be available at all grades not included in the accountability or summative program. Interim accountability assessments for the next two years will be administered in Grades 4, 8, and 12, and will consist of traditional multiple-choice, open-ended and essay tests; performance events (administered in one sitting and requiring an individual or group performance); and portfolios (collections of student work).

The state of Kansas embarked on the Kansas Mathematics Improvement Program as a major part of the Kansas State Board of Education's school restructuring process. Central to this improvement program is the specification of standards paralleling those identified in the National Council of Teachers of Mathematics *Curriculum and Evaluation Standards for School Mathematics* (1989) and assessment involving all students in Grades 3, 7, and 10. Other components of the mathematics improvement program are partnerships among business and industry, parents, and educators to review mathematics standards; staff development to assist teachers in acquiring additional skills and techniques in teaching mathematics; student improvement plans for those students who do not meet the standards; a review of existing teacher education programs for preparing teachers and of certification requirements for teaching mathematics; and redesign of the process for accrediting schools to emphasize outcomes and performance (Kansas State Board of Education, 1991). Other states such as Arizona have taken a similar approach of specifying goals and then implementing some form of assessment to determine whether those goals are being achieved.

Other states have taken additional action. Louisiana mandated in 1984 that all students who graduate from high school have to have completed three years of mathematics including Algebra I and II and Geometry. But because of the high failure rate of Louisiana students in Algebra I, steps were taken by the state to lower the requirements. An integrated algebra and geometry course was added to the Louisiana high school curriculum that could be used by students to satisfy one of the three mathematics credit requirements.

A number of states have based a significant part of their reform efforts in mathematics on student assessment. Some states have raised the stakes on these assessments by requiring students to score at a certain level on the assessment as one condition for high school graduation. State-controlled education systems, such as Louisiana's, have gone further and specify what courses students must pass in order to graduate. The reform efforts in most states consist of a number of components, such as those used in Kansas. What is different in California is the development of an infrastructure over a number of years that can further change. Important to this infrastructure is the very active California Mathematics Council, the California Mathematics Projects, and the California Assessment Program. Because of the tradition of local control in the state, the California Department of Mathematics has to depend upon these groups and cooperate with them to institute change.

California *Mathematics Frameworks*

Restructuring mathematics education in California, as represented in the changing recommendations in the *Frameworks*, is more like a wide stretch in a river or a moderate rapids than a sharp turn or a fork. *Frameworks* have been issued for thirty years. Language in the first *Framework*, produced in 1963 in the middle of the "New Math" era, conveys the importance of a technologic:' culture, student-centered learning, dynamic instruction, and students seeking meaning in their study of mathematics. Much of the same conception of teaching and learning is portrayed in the *Framework* previewed in 1991 by emphasizing mathematical power as thinking, communicating meaning to students so that they have a greater sense of purpose in learning mathematics, and encouraging students to assume more responsibility for their own learning. The conception of mathematics as a highly structured body of knowledge has evolved into a concept of mathematics as a changing body of knowledge to be investigated by students and to benefit all students in an increasingly diverse population. To provide a sense of the evolution of California's curriculum recommendations, a short review of the six *Framework* documents is presented.

The vision for reform of mathematics in the state is recast and new guidelines for decision making are established about every seven years by the curriculum framework. Three-to-four years prior to adopting textbooks for Grades K-8, the superintendent appoints a mathematics advisory committee to develop a document that can be shared with textbook publishers and then assists the adoption committee in approving the textbook series. Over the years the *Frameworks*, as they have become known, have been supplemented by documents prepared in the interim to provide more detail and more direction on the teaching of mathematics. The first *Framework* in 1963 was prepared for Grades K-8. The first *Framework* for Grades K-12 appeared in 1974.

The 1963 *Strands Report*

Recommendations consistent with the most recent *Framework*, published in 1991, appeared in the first *Framework* in 1963 (California State Department of Education, 1963). Also known as the "Strands Report," the original document signed by Max Rafferty, who was superintendent of public instruction at the time, defined four major emphases for change in the content of the mathematics curriculum in kindergarten and Grades 1 through 8: more emphasis was to be placed on the structure of mathematics; the elements of synthetic and coordinate geometry were to assume a central role; the language of sets was to be introduced; and mathematics and its applications related to the entire curriculum. The document noted that skills and strands were to be tied together by a few basic strands (Numbers and Operations, Geometry, Measurement, Application of Mathematics, Functions and Graphs, Sets, The Mathematical Sentence, and Logic). Preparing students to live in a technological culture was the primary motivation for the recommendations. It was recommended that topics not be tied to specific grade levels, but "linked with the pupils' mode of thinking." Good mathematical instruction was described as dynamic -- encouraging students to make conjectures and guesses, to experiment and formulate hypotheses, and to seek meaning.

The 1972 *Mathematics Framework*

The second *Framework* (California State Department of Education, 1972) reinforced what was included in the first. The 1972 *Mathematics Framework* was the culmination of the work of an advisory committee that met for the first time in January, 1967, and delivered a preliminary report the same year. The recommendations were used as criteria for adopting mathematics textbooks and materials for the five-year period beginning with the 1970-71 school year. The *Second Strands Report, Mathematics Framework, California Public Schools, Kindergarten through Grade Eight*, published in 1972, went beyond specifying content and described in some detail methods for teaching and learning mathematics. This document was prepared by a 10-member committee consisting of 3 mathematics professors, 5 district mathematics supervisors or staff, 1 mathematics teacher, and the mathematics consultant to the California Department of Education. This *Framework* was signed by Wilson Riles, the superintendent at the time.

The second *Framework*, like the first, was not designed to be prescriptive but to clarify subtle and crucial issues in curriculum planning and to make recommendations on these issues. The 1972 *Framework* was prepared for the use of writers, publishers, and teachers. The strands were organized into two categories. One identified the "basic cognitive subdivisions of the mathematics curriculum" (p. 2) and included Numbers and Operations, Geometry, Measurement, and Statistics and Probability. The second focused on the "catalysts, or processes which facilitate mathematical analysis to some degree in every mathematical enterprise" (p. 3). Strands in this category were Applications, Sets, Functions and Graphs, Logical Thinking, and Problem Solving. Users were cautioned to avoid isolating single strands, "A satisfactory curriculum will display and use these interdependent strengths in its development" (p. 3). The expectation for a successful implementation of the strands was that students would be prepared to tak' a modern algebra course in ninth grade. However, the hope was that as many pupils as possible would be prepared to take the algebra course in Grade 8.

The strands were specified on the basis of knowledge of recent research on the mathematics that could be learned by elementary age students and on the appropriate methods to teach it. This cumulative evidence led the committee to stress that "mathematics learning must involve each pupil in a participatory activity employing manipulative materials as well as pure cognitive exercises" (p. 3). Tying mathematics to its applications in other disciplines was viewed as important. Emphasis was placed on appreciating the abstract quality of mathematics for its applications in a broad spectrum of situations. A basic assumption was that recognizing and using basic principles, stated in pure mathematical language or as an abstract mathematical concept, would increase the students capability to solve a variety of problems in all disciplines. The introductory chapter closed with a statement on the continuing need to make changes in the curriculum, "The final word on mathematics education will never be written because society continually places new demands on mathematics" (1972, p. 4).

Free and open investigations were considered good pedagogy in the 1972 *Mathematics Framework*. Open communication between teacher and pupil was encouraged and the value of students learning from each other in group work was noted. Handling an object, comparing objects, or placing objects in various relationships to each other as different ways of using manipulatives were regarded as important for facilitating learning. The use of mathematically purposeful games, the analysis of experiments, and the reinforcement of previous mathematical experiences were also valued for facilitating learning.

The 1974 *Mathematics Framework*

An Ad Hoc Mathematics Framework Committee was appointed in October, 1973, to write a set of creative guidelines for teachers, authors, and publishers to develop instructional materials. The third *Framework*, published in 1974, noted changes in emphasis from previous *Frameworks* rather than changes in substance. Increased emphasis was recommended on the application of concepts, computational skills along with the structural aspects of mathematics, the improvement of attitudes, the use of the metric units, the total concept of decimal numbers, and problem-solving skills. Less emphasis was placed on the numeration systems, computation of fractions, and set theory. The 1974 *Framework* made the point that the climate and environment for learning mathematics should provide students experiences with objects, a means of communication, and opportunities to be involved in activities. Learning was identified as a group experience -- an important context in which students would learn from each other.

The 1980 *Addendum*

Much of the 1974 *Mathematics Framework* was reproduced in 1980 along with an addendum. Rather than prepare a complete framework, a supplementary document was written to present problem solving/applications as the "umbrella" over all other skills and concepts. Heavily influenced by the *Agenda for Action* (National Council of Teachers of Mathematics, 1980), the *Addendum* (California State Department of Education, 1982*a*) clarified the importance of four topics: Problem solving/applications was elevated from being one of several strands to the primary reason for studying mathematics. The language was changed to refer to problem solving/applications as a strand while other topics were designated as skills and concept areas to emphasize their subordinate role. Calculators/computers, a new area, assumed the role previously held by problem solving/applications in the earlier documents when they were included in the concepts and skills areas. Two other sections were added to the document that also reflected the changing times. A section on proficiency standards and remediation in mathematics was a response to the public concern in the mid-1970s with the lowering of basic skills performance of students, the Back-to-Basics movement. A section was also added on staff development that recognized its importance for ensuring the implementation of the concepts embodied in the 1980 *Mathematics Framework.*

The 1985 *Mathematics Framework*

The 1985 *Mathematics Framework* (California State Department of Education, 1985) was described by Superintendent Honig as a statement of philosophy and the vision "that *every* student can enjoy and use mathematics to real advantage and that the power of mathematical thinking is not reserved for only an academic elite." This inclusive statement represents a major difference in the rhetoric compared to the initial *Frameworks* of the 1960s and early 1970s. Major initiatives in testing procedures, textbook development, and teacher professional development were seen by the superintendent as critical to achieving goals for the mathematics curriculum outlined in the 1985 *Framework.* These three areas were highlights of the state's strategy. A new test in mathematics for the California Assessment Program was being developed, instructional materials were to be adopted according to the *Framework* specifications in 1985-1986, and the superintendent was communicating with university and college leaders to ensure that new teachers would be prepared to teach the program outlined in the *Framework.* The 1985 *Framework,* the first of Mr. Honig's era, made change a high priority. Prior to this time, the *Framework* had established guidelines for the textbook adoption process and little else. The *Frameworks* were not really regarded as vehicles for change. Mr. Honig's administration made curriculum change the engine for education reform. The curriculum was designed to effect change. Mr. Honig took the position that the state had responsibility for determining the curriculum.

The 1985 *Mathematics Framework* encouraged a spirit of inquiry and an intellectual curiosity toward mathematics throughout the school years. As in the earlier *Frameworks,* the importance of a knowledge of mathematics in other disciplines was stressed. But unlike the other documents, advances in technology were offered as a basis for rethinking what should be emphasized in the curriculum and for including calculators and computers in pupils' mathematical experiences. Integration of the knowledge of mathematics, emphasized in the earliest *Frameworks,* was recast in the concept of *mathematical power.* "Mathematics power, which involves the ability to discern mathematical relationships, reason logically, and use mathematical techniques effectively, must be the central concern of mathematics education and must be the context in which skills are developed" (p. 1). The concept was further explained by describing students who are mathematically powerful as: "(1) having an attitude of curiosity and willingness and ability to probe, explore, experiment, make conjectures, and persevere; (2) possessing the capacity to add, subtract, multiply, and divide whole numbers, decimals, and fractions with facility and accuracy; (3) being able to extract information from data; and (4) capable of dealing successfully with problems" (pp. 1-2).

Five major areas of emphasis noted in the 1985 *Framework* were problem solving, calculator technology, computational skills, estimation and mental arithmetic, and computers in mathematics education. Seven strands of mathematics formed the major organizational structure for content. The strands were compared to the visible spectrum of colors, in which several color bands exist that lack clearly defined boundaries between them (p. 8). The seven strands -- Number, Measurement, Geometry, Patterns and Functions, Statistics and Probability, Logic, and Algebra -- defined the content for the different grade ranges divided into K-3, 3-6, 6-8, and 9-12. By contrast with the structure of the 1972 *Framework*, the 1985 version did not differentiate between cognitive and process categories. Rather than distinguishing between psychological dimensions, the 1985 *Framework* was organized more around degree of emphasis. The seven strands in 1985 were all represented in the 1972 strands. However, problem solving and applications, two strands in 1972, were considered overriding goals to be emphasized across the strands. The 1972 strand of Sets did not appear in the 1985 document, a lost artifact of the New Math era.

In the instruction of mathematics, as described in the 1985 *Framework*, student understanding of fundamental concepts was assigned primary importance, rather than memorization. Concepts and skills across the strands and over the grade levels were to be continually reinforced and extended. Students were to be actively engaged in solving problems, experiencing four distinct steps in the process, and accumulating a collection of strategies. Situational lessons, using challenging problem contexts of significance to the students, were to be used to develop and reinforce mathematical concepts and skills. Concrete materials were to be used K-12 to help students connect their understandings about real objects and their own experiences to mathematical concepts. On-going diagnosis and assessment were to be used to address the diverse needs of students. Small cooperative learning groups were to be used to increase students' opportunity to interact with materials. The *Framework* advocated the definition of mathematical terms in language meaningful to students and their lives. Stimulating questions and responses were to be used by teachers to engage students actively in mathematics lessons and to improve their understanding.

A fundamental change was recommended in the 1985 *Framework* for restructuring the 9-12 mathematics curriculum to orient it toward all students taking four years of high school mathematics. "The high school mathematics program should make it possible for students to take mathematics during all four years and should provide counseling to encourage students to do so (California State Department of Education, 1985, p. 33). At the time, the high school mathematics curriculum was organized on the basis of a traditional two-track system. Students in the college-preparatory track generally would take a year of algebra, a year of geometry, a second year of algebra, and then a year of analysis, trigonometry, and other topics preparatory to calculus. Some students who began this series in the middle grades, or were accelerated through the sequence, would take calculus in the eleventh or twelfth grades. Students not intending to go to college were directed into general mathematics courses with a strong computational emphasis in which arithmetic was applied in consumer and routine situations. Many students beginning their high school mathematics experience with a general mathematics course never gained exposure to algebra or more advanced mathematics.

Math A, Math B, and Math C were conceptualized for students not prepared to take algebra in ninth grade. A Math A course was designed to serve non-college-bound students by giving them experiences working with the fundamental concepts and skills required in a technological society, while increasing their understanding in measurement, geometry, statistics and probability, logic, and algebra. Students who successfully completed Math A were then to be given the option of going on to take Algebra I in tenth grade and to continue with the standard college preparation sequence or to take Math B. Math B, designed for those students still having trouble after Math A, extended the content in that course. Students successfully completing Math B were to have the equivalent of an Algebra I course and the option of continuing in the standard curriculum by taking geometry in Grade 11 or going on to Math C. For students who did not intend to go to college but were still interested in taking a third year of relevant mathematics, a Math C course was envisioned. In addition to the standard algebra, geometry, and advanced mathematics courses sequence and the Math A-B-C sequence, two remedial courses were outlined -- one for students who had not mastered the skills covered in junior high school and one for students who had not mastered the skills taught in elementary school.

Some of the ideas included in the 1985 *Mathematics Framework* influenced the development of the NCTM's *Curriculum and Evaluation Standards for School Mathematics* (National Council of Teachers of Mathematics, 1989). The imperative of mathematical power for all students in a technological society was incorporated into the *Standards*. The four overriding standards of problem solving, reasoning, communications, and connections corresponded with principles expressed in the California 1985 *Mathematics Framework*. Fundamental differences between the two documents included how problem solving was interpreted and the structure of the high school curriculum. In the *Standards*, problem solving is viewed as fundamental in all mathematics, as a means of doing and learning mathematics. As a consequence, steps in solving problems or strategies for devising answers are not presented. The *Standards* recommend a core curriculum for Grades 9-12 for all students of a minimum of three years of mathematics. The differences in the content to be covered by students should vary with the degree of mathematical sophistication and abstraction rather than in the variation in topics. To a certain extent, California's Math A-B-C sequence represents movement toward a core curriculum, but still defines specific tracks and retains the traditional college preparation sequence of Algebra I, Geometry, Algebra II, precalculus, and calculus.

The 1991 *Mathematics Framework*

A preview edition of the most recent *Framework* was released on November 8, 1991 (California State Department of Education, 1991a). Consistent with the state's effort to move the mathematics curriculum towards greater effectiveness, the 1991 *Framework* recommends noticeable changes compared to the 1985 *Framework*, while still retaining many of the basic ideas from that and other documents. The current version recognizes the contributions of the NCTM *Standards*, *Everybody Counts* (National Research Council, 1990), and other reform documents published both in California and elsewhere. The concern for equity in mathematics education is much more apparent than in previous *Frameworks*, a response to the increasing diversity in California's population. Mathematical power for all students becomes the over-arching goal for the curriculum. Problem solving and applications, as terms, are not used but their meaning is subsumed in the goal of educating students who will be mathematically powerful. The 1991 *Framework* simply states, "Mathematically powerful students think and communicate, drawing on mathematical ideas and using mathematical tools and techniques" (p. 2). Thus, mathematical thinking, mathematical ideas, communication, and tools and techniques become the critical dimensions of learning mathematics. Along with this, mathematics is to be presented so that students have a sense of purpose. Although this does not imply that all mathematics that is learned has to have a direct application, students should be learning mathematics for clear reasons and not as a series of meaningless exercises. Students are also clearly expected to take more responsibility for their own learning.

The impression of the mathematics curriculum presented in the 1991 *Framework* is more coherent and unified than that of previous years. The term investigation is used to refer to doing large areas of work. Completeness is achieved when a student demonstrates all the dimensions of mathematical power in carrying out an investigation. Large chunks of curriculum are referred to as units. Unifying ideas, important and deep mathematical ideas, are themes or threads that hold the curriculum together across the strands and grade levels. Pursuing a more holistic approach to the mathematics curriculum, the 1991 *Mathematics Framework* encourages teachers to look at mathematics and to organize their instruction of mathematics in new ways. The document specifies the characteristics of empowering mathematics programs: students learn mathematics; they fully participate; they assume responsibility for learning; teachers facilitate learning; manipulatives, calculators, and computers are regularly used; students frequently share and discuss ideas; students reflect their thinking orally and in writing; assessment is integral to instruction; the program is developmentally appropriate; it develops a positive predisposition toward mathematics; and it introduces computational procedures only when needed.

Strands continue to be the main means of conveying content and relating to previous *Frameworks*. Appearing in 1991 for the first time is a Discrete Mathematics strand. The Functions strand replaces the Functions and Patterns strand. Patterns, in 1991, are considered to exist in many of the strands and are not thought of as only existing in a single Patterns strand. The Logic strand has become Logic and Language, emphasizing the importance of language in clarifying thinking and making valid arguments. The other strands -- Algebra, Geometry, Statistics and Probability, Measurement, and Number -- retain their titles. However, some of these have changed their meanings to convey a notion of relationship to other strands. The limitations in thinking of the curriculum as separate strands are dealt with by including unifying ideas such as proportional reasoning, patterns, and multiple representations.

A large effort is made in the 1991 *Mathematics Framework* to discourage any form of tracking and to work toward a core curriculum in Grades 9-12. Math A and B still exist as auxiliary courses, but a central high school curriculum of three courses is recommended, each drawing from all of the strands. The expectation is that all high school students complete Course 1, Course 2, and Course 3. Math A is designated as a transition course for those students completing Grade 8 without being deemed ready for the core curriculum. The hope is that most students completing Math A will then take Course 1. Those who do not will take Math B before entering Course 1. Math A and B are no longer viewed as a viable alternative to a college-bound track, but are now viewed as a funnel to direct students into the core curriculum, regardless of their higher education intentions. Exceptional students could enter Course 1 after Grade 7. After completing the three years of the core curriculum, these students are to have the option of taking a probability and statistics course or a pre-calculus course followed by a calculus course.

Analysis Across the *Frameworks*

The *Frameworks* over the years represent less a radical variation from the first *Frameworks* than an evolution. The 1991 *Mathematics Framework* builds upon the 1985 *Framework* and prefigures much of what has been included in other documents such as the NCTM *Curriculum and Evaluation Standards for School Mathematics* and the *Professional Standards for Teaching Mathematics* (National Council of Teachers of Mathematics, 1991). The 1985 *Framework* laid out the strands. The 1991 *Framework* goes into more depth on what mathematics students should know and provides a structure to guide teachers in thinking about the curriculum. The unifying ideas in the 1991 *Framework* are presented for the purpose of helping teachers understand, for example in the middle grades, that proportional reasoning, multiple representations, and patterns and generalizations can be used as a thread for organizing activities throughout the school year and during the transition years between elementary and high school mathematics education.

A perspective on the extent of change in the *Frameworks* recommendations can be obtained by focusing on one topic across the different documents. The language used to describe the topic, the expectations for what students are to know, and the methods for presenting material all reveal the essence of the recommendations and the direction in which these recommendations press for reform. When this is done, the 1985 *Framework* differs little from the earlier recommendations whereas the 1991 *Framework* represents a much more dramatic change.

The 1985 *Framework* included a listing of traditional content topics and seemed more a collection of essays than a coherent curriculum presentation. The 1985 *Framework* stressed problem solving and estimation, but was not viewed as that radical by publishers or others until all of the mathematics textbooks on California's list were rejected in 1986 -- a move that took the publishers by surprise. This rejection was a political statement, a call for change. It was an expression of an attitude evolving in the Department, rather than evidence that the curriculum recommendations were dramatically different from those of the previous *Framework*.

To illustrate the evolution of the recommendations over time, the Number strand will be considered in more detail across five of the *Frameworks*. All of the *Frameworks* have had a Number and Operations strand in some combination: Number and Operations in 1972, Number in 1985, and Number in 1991. The 1972 *Framework* offers advise on how numbers should be presented, "The system of rational numbers should be presented as a system of expanding ideas. In such a presentation the learner first encounters the set of whole numbers {0, 1, 2, . . . }" (p.23). Unifying ideas were offered, but these represented specific ideas related to numbers: order, counting, and betweenness; operations and their properties; identity elements; numeration systems; and mathematical sentences.

In contrast, the 1985 *Framework* does not include any unifying ideas and varies little from the 1972 document. What difference that it does communicate is the need to base learning on what students already know: "It is important that early experiences in school give meaning to the counting sequence and expand on what the students bring to school" (CSDOE, 1985, p.16). The advice on presenting numbers echoes the phrases and sequence used in 1972 without some of the rigor, "The system of numbers should be presented as a system of expanding ideas, starting with the counting numbers and proceeding to the whole numbers, nonnegative rational numbers, the integers, all rational numbers, the real numbers, and the set of complex numbers" (p. 8).

A marked variation is evident in the 1991 *Framework*. Number and numeration are not delineated into subsets of the number system; rather the application and representation of numbers are the focus. Knowledge gained through experience clearly is advocated where students will probe their understanding more deeply -- there is no mention of a sequence for presenting the system. "Their [students'] experiences in school will gradually expand and deepen their understandings of number and numeration. They will develop number sense and facility in doing things with numbers" (p. 88). Unifying ideas appear in the 1991 *Framework*, but with a meaning entirely different from their presentation in 1972. The unifying ideas are not the actions that operate on the elements of the system, but are actions that apply across systems and topics. The unifying ideas for K-5 in 1991 are: How many? How much?; finding, making, and describing patterns; and representing quantities and shapes.

This is but one example. What it demonstrates is that over the six years from 1985 to 1991, views of the mathematics curriculum by those who prepared the *Framework* had changed. This change represents movement in the reform thinking over that time period from a more superficial change in how the mathematics should be taught to a deep conceptual shift in thinking about what the essence of the curriculum should be and how important it is that the curriculum take into consideration students' experiences (past, present, and future).

Other evidence of a new climate for change between 1985 and 1991 was the process for preparing the 1991 *Mathematics Framework*. A conference that was held in the fall of 1988, to address issues related to development of the 1991 versions of the *Framework*, was attended by representatives from 35 textbook publishers, mathematics educators in the state, and national mathematics education authorities. The notion of eliminating textbooks altogether and using instead individual units of instruction organized more like a story centered around a plot was strongly supported. This thematic approach for organizing the curriculum greatly influenced the writing of the 1991 *Framework*. As with previous *Frameworks*, drafts of the 1991 *Framework* were distributed around the state for review. Compared with other years, however, the number of drafts was greatly increased. In 1985, 300 drafts were sent to reviewers. For the 1991 versions, interest in curriculum reform had increased to such an extent that 2 000 copies were distributed for review.

Most likely, the 1991 *Framework* will provide the vision for the 1990s. In 1992 there were no plans to develop another mathematics framework in the mid-1990s. The Department's view is that the *Frameworks* have been useful as political documents for communicating a vision and providing leadership, but that the *Frameworks* alone have been insufficient to result in real change. The thrust for the 1990s is to execute this vision of the 1991 *Framework*. This will require the development of a coordinated program that includes assessment, teacher professional development, and school-based change as major components.

THE CALIFORNIA ASSESSMENT PROJECT

The California Assessment Project (CAP) is integral to the overall strategy to engineer change in mathematics education in California. The program is mandated by the state legislature to fulfill assessment requirements set by the state for districts and schools. In the spring of 1990, the California Assessment Project administered tests in reading, written expression, and mathematics in Grades 3, 6, 8, and 12. Science and history-social science were assessed in Grade 8 and direct writing was assessed in Grades 8 and 12 (Pandey, 1992). Tests are administered annually and scores are reported by school and district. All students are tested using a nonoverlapping item-sampling design. (Earlier in its history, in 1980 for Grade 3, the 360 mathematics items administered were divided among 30 unique test forms along with the reading and written-expression items.) The testing time for any one student is limited to one class period, generally 40 to 50 minutes long.

The assessment program has been in existence for a number of years. In 1972, the CAP began developing new tests for Grades 3, 6, and 12. Advised by a statewide committee, content specifications were developed. Then items were leased from a test publisher to match these specifications. Prior to this time, the California Department of Education had contracted with Stanford University to develop what became known as the "State of California Inventory of Mathematical Achievement" (SCIMA) (see California State Department of Education, 1972, p. 22). The three part test -- Grades 3, 6, and 8 -- comprised the model for the state assessment.

In 1975, the CAP began to develop its own items beginning with Grade 3, then Grade 6 in 1982, Grade 8 in 1984, and Grade 12 in 1987. The department was assisted by an advisory committee of mathematics educators from around the state. By 1987, all of the mathematics tests administered by CAP were developed by the program. The general content categories for developing the CAP items paralleled the existing *Mathematics Framework*. The mathematics skill areas assessed in 1984 for Grade 8, along with the percentage of items, were Numbers (15 per cent), Operations (15 per cent), Algebra (15 per cent), Geometry (15 per cent), Measurement (9 per cent), Probability and Statistics (8 per cent), Tables, Graphs and Integrated Applications (7 per cent), and Problem Solving (16 per cent). The Survey of Academic Skills, administered to Grade 12 students in 1984 had two major parts -- Problem Solving/Reasoning (25 per cent) and Understanding and Applications (75 per cent). The Understanding and Applications section of the assessment was further divided among Numbers and Operations; Patterns, Functions, and Algebra; Data Organization and Interpretation; Measurement, Geometry, and Spatial Relationship; and Logical Reasoning.

Districts are required by the California Pupil Proficiency Law, effective in 1976 and refined in subsequent years, to judge the proficiency of students in Grades 7, 9, and 11. The law was phrased in broad terms but did mandate criterion-referenced test-score interpretations. A 1980 report *Proficiency Assessment in California* (California Department of Education, 1980), noted that a preponderance of objective and paper-and-pencil instruments were being used by districts to satisfy this requirement. Eighty per cent of the tests were locally developed, criterion-referenced tests. In 1982, the *Guidelines for Proficiency Tests* (California State Department of Education, 1982b) was published to assist districts in identifying their strengths and weaknesses by using existing, locally developed tests and then, on the basis of the test scores, to take steps to make improvements. These actions toward proficiency testing reflected the national trends at the time for stronger accountability provisions and a return to the basics. Although the statutes for local testing were still on the books as of 1991, the California Assessment Program in recent years has become more prominent as a means of assessment. The CAP serves as one of the Department's major vehicles for change.

In 1987-88, a significant change took place in the CAP version of the test: open-ended questions were piloted at Grade 12 for the first time by the program. The open-ended questions that were developed took 12 to 15 minutes for students to answer; took into consideration current thinking about mathematics, current understanding of how children learn, and good curriculum practice; and required students to write. For example, one item piloted showed two geometric figures, an isosceles right triangle and a hexagon with a section missing, each on a 7-inch-by-6-inch grid, and asked the students to write a set of directions so that another student could draw the figures exactly without seeing them. A random sample of 2 500 responses -- approximately 500 responses to each of five questions -- out of a total of 240 000 responses were scored. School districts had access to the responses of their students and could score these on their own. A seven-point rubric was used to distinguish among the responses: 6 and 5 indicated competence; 4 and 3 indicated a satisfactory response; and 2, 1, and 0 indicated inadequate responses. A strong motivation for the CAP in using open-ended questions was to better align the assessment program with the 1985 *Framework* and to influence classroom practice (California State Department of Education, 1989). During the 1988-89 school year, open-ended questions became a regular part of the Grade 12 mathematics assessment.

Assessment reform became a major mechanism for exerting pressure on schools to make curriculum change. The Department conducted conferences around the state in 1988 to inform people of the need for changes in assessment and the importance of including more "authentic" forms of assessment. Known by the term *Beyond the Bubble*, these conferences were as political as they were informative. Influential people such as state legislators, national experts, decision makers, and other key people were invited to hear about and discuss assessment. One purpose of the California Assessment Program for conducting these conferences was to gain public support for change.

A Sampler of Mathematics Assessment (California Department of Public Instruction, 1991b) was released in 1991 to describe and illustrate the four types of assessment planned for CAP: open-ended problems, enhanced multiple-choice questions, investigations, and portfolios. This booklet was prepared for elementary and secondary mathematics teachers, to assist them in making changes in their classroom instruction and student assessment practices. It was released just prior to, and refers to, the 1991 *Framework*. The major objective for changing assessment practices, as for changing the curriculum, is to enable students to become mathematically powerful by involving them in worthwhile mathematics tasks.

Assessment will continue to be central to future plans for reform. For the first time, in the spring of 1993, the CAP will assess students in Grades 4, 8, and 10 and report individual scores. Although still in the planning stage, the probable model will use some form of matrix sampling for administering different forms of the assessment to different students, but will have the tasks calibrated so that scores by individual students can be compared. Scoring of the assessment tasks will be done by teachers and tied to their professional development. This will be another component of the overall strategy for effecting reform. Some of the performance-based assessment will be structured on the basis of "replacement units" developed through the state director of mathematics. The scoring of the student responses will be done by teachers, giving them a greater understanding of what is expected and how students respond to these expectations.

TEACHER PROFESSIONAL DEVELOPMENT

Critical to the overall strategy of the current reform effort in California is the active participation of teachers. Over half of K-12 California teachers -- approximately 120 000 -- teach mathematics. Even with the *Frameworks* and annual assessments, contacting teachers spread over the 1 000 mile length of the state becomes a major challenge. One strategy for reaching teachers has been to organize regional teacher training institutes and leadership development workshops through the California Mathematics Projects. Another strategy has been to support the development and implementation of curriculum replacement units.

California Mathematics Projects

In 1992, 17 mathematics projects were in operation through institutions in the University of California and California State University systems. The primary mission for these California Mathematics Projects (CMP) has been to gain the active involvement of teachers and to develop a cadre of teacher leaders. Since the CMP's modest beginning in 1983, approximately 5 000 teachers have participated in summer institutes. These teachers, in turn, have reached out to other teachers to the extent that nearly 75 per cent of the those who are teaching mathematics in the California schools have at least an awareness of the CMP and its work.

A director, supported by a secretary, administers the California Mathematics Projects out of the University of California central offices in Oakland. The director works with the site directors and coordinates their meetings, but sites operate with some autonomy. The CMP director meets periodically with the site directors, making regular site visits around the state. The project has grown from two pilot sites in 1983 to the 17 current sites. The total number of sites is not expected to exceed 20.

The CMP administrative office is funded primarily as a line item in the state budget. A total of $1.5 million in state funds goes toward supporting this central office and the regional sites. Each of the 17 sites has its own director who oversees the summer institutes, recruits teachers, plans the school year activities, and writes proposals for generating funds. In addition to funds from the state, the typical CMP program receives major grants from the National Science Foundation or other sources that help finance the local projects. School districts have funds available to them from the federal Eisenhower Program. This has been an important source of support for districts in financing professional development programs for teachers. The director of mathematics for the state has also used the modest funds at the disposal of his department to help finance the development of replacement units and workshops to train teachers in their use.

A project originates at a site when the CMP director identifies a region in the state where there is a perceived need. The director then meets with a number of persons with a real or potential stake in the professional development of mathematics teachers. These stakeholders then have responsibility for structuring a project to meet local needs and restrictions. For example, a northern project holds residential summer institutes for ten days where teachers work from sunrise to sunset in a rustic camp and sleep in sleeping bags. Other sites in the southern part of the state have difficulty getting teachers for a full four weeks in the summer because of other commitments. These sites have three-week summer institutes and then will hold one or two weekend retreats during the school year. The general model is to have teachers attend a four-week summer institute with some follow-up during the school year. A teacher who attends a summer institute is to work with others in his or her district during the school year. Teachers are paid approximately $650 for participating in the three- or four-week summer institutes. These funds are provided by the site, sometimes with the help of districts. Common to all sites is the general philosophy of "teachers teaching teachers." University mathematicians who might be project directors were also included among the teacher presenters.

Over the eight years that the California Mathematics Projects have been in existence, they have formed an infrastructure across the state that has become integral to the change process. The projects have successfully created a leadership cadre among the teaching force. As reform in the state has developed greater coherence through revision of the frameworks and the search for new forms of assessment, the California Mathematics Projects have become central to changing the system. Not only were the projects used as a means of disseminating information and curriculum changes to teachers, but they also provided a mechanism by which teachers could contribute their input into the system.

Strengthening the teaching profession has been an underlying commitment of the California Mathematics Projects. The basic assumption is that if teachers become more responsible professionally for the curriculum and student outcomes then greater advances will be made. Generally, a district setting standards for student learning will do this procedurally, by specifying measurable objectives. The CMP assumes that if professionally responsible teachers develop standards for student learning, these standards will reflect who the students are, student diversity, and what students should know about mathematics. As a consequence, the CMP has worked closely with the California Mathematics Council, a professional organization of mathematics teachers affiliated with the National Council of Teachers of Mathematics. Many of those who have leadership positions in the California Mathematics Council have been associated with the CMP.

In 1992, the CMP is working with its 5,000-teacher cadre to reach regional consensus on rubrics that will be used in scoring the open-ended tasks included on the tests administered by the California Assessment Program. The fact that teachers from the CMP were willing to score the open-ended tasks was significant in persuading the state legislature to fund the development and administration of such tasks in the early 1990s. Also, there is some evidence that reform is reaching students through the CMP channels. At their meeting with the CMP director, the site directors are asked to bring examples of student work that exemplify the targeted reforms. In 1991, site directors brought more examples (which included student writing and student explanations of their thinking) than had been produced in all of the previous years. Although this is only a very small piece of evidence, it is one indication that some movement is being made toward the desired goals.

Replacement Units

Textbooks are very influential in determining what mathematics is taught. The *Frameworks* in California have been developed in an effort to influence what is included in the textbooks that are used in the state. However, the market created by what teachers and schools are willing to buy also influences the instructional materials used. One objective of the Department of Education is to build a demand for change in the materials that coincide with the latest *Framework*. The California Mathematics Project operates within the system to provide professional development experiences for teachers. But because of the limited time that teachers have to develop curriculum and to translate the recommendations into practice, some specific examples of recommendations directly applied to the classroom were needed.

The development of replacement units was one idea that reflected the Department's sensitivity towards teachers' perspectives. This idea grew out of conversations among the director of mathematics, the director of the California Mathematics Projects, and others at the 1988 fall symposium held to plan for the development of the 1991 *Framework*. It was based on the belief that for real change to take place, teachers had to have available to them large "chunks" of curriculum that integrated the recommended changes and could be directly inserted into the sequence of topics normally taught during the year. The practice of simply supplementing existing materials or giving teachers new activities did not result in the curriculum changes that encouraged students to become more active in their own learning through such activities as investigation and data collection.

The director of mathematics and his staff developed the model for these replacement units. At the end of 1989, California contracted with the Technical Education Research Center (TERC), of

Cambridge, Massachusetts, to develop a unit on fractions for Grade 5. The "Seeing Fractions" replacement unit was completed at a cost to the Department of $150 000. A series of workshops were conducted during the summer of 1990 to train elementary teachers to use this new unit. The original expectation was to inservice 1 000 teachers. The demand was so great that a total of 1 500 Grade 5 teachers attended "Seeing Fractions" workshops led by Grade 5 teacher leaders who were recruited by the Department's mathematics unit. Since its publication, 5 000 copies of "Seeing Fractions" have been sold, many to those outside of California.

Encouraged by the success of its first replacement unit, other units were sought. Marilyn Burns, a teacher and an educational entrepreneur, had completed work on a Grade 3 multiplication unit. The Department covered the cost of publishing the unit and funded two large workshops, one in the southern part of the state and one in the north, to introduce it to teachers. Approximately 200 teachers attended each workshop, which were held in the fall of 1991. Smaller workshops, funded by a grant from Exxon, on the multiplication unit will be conducted in 1991-1992 around the state until about 2 000 teachers have been inserviced. The cost for a workshop on one of the replacement units is about $1 700 for 50 teachers to attend.

A third replacement unit on measurement and scaling, "My Travels with Gulliver," was produced by Glenn Kleinman and Betty Bjork for the Education Development Center at Newton, Massachusetts. A fourth replacement unit, "Growth Patterns," has been developed for Grade 8 by a project directed by Elizabeth Stage and funded by the National Science Foundation.

The Interactive Mathematics Project, being developed through the San Francisco State University and the University of California-Berkeley, is sponsored by the California State Department of Education among other groups. Major funding is provided by the National Science Foundation, but additional funds come from the U.S. Department of Education's Eisenhower Funds. Beginning in 1989, the Interactive Mathematics Project (IMP) developed a three-year secondary school mathematics curriculum to replace the traditional sequence of courses. Initiated in response to a request for proposals from the California Postsecondary Education Commission to design a curriculum that would drastically revamp the Algebra I-Geometry-Algebra II sequence, the project has developed a curriculum based on problem solving, reasoning, and communication as major goals. Statistics and discrete mathematics are used throughout the curriculum, which also gives technology an important role. This problem-based curriculum is constructed around units that treat a central problem or theme and that require four-to-eight weeks to complete. The learning of concepts and skills is driven by this central focus. Less traditional forms of assessment are being used, such as open-ended investigations, called Problems of the Week, and portfolios. One obstacle effectively addressed by the project was the University of California requirement that students had to complete the three courses of Algebra I-Geometry-Algebra II to be admitted to system institutions. The project made a special request, granted by the University of Californi system, to accept the three years of mathematics as provided by the IMP as satisfying these requirements. The Interactive Mathematics Project represents another way, besides the replacement units, in which reform recommendations are being translated into curriculum materials that will be available to teachers and schools to further change.

SCHOOL-BASED CHANGE

A major effort by the Director of Mathematics and his staff was initiated in the summer of 1991 to focus on change in specific schools. The Middle Grades Mathematics Renaissance project began working with two teachers from each of 78 middle schools. The schools selected for participation in the project were chosen from 200 that were asked to apply. Seven teachers, to be teacher leaders for the approximately 150 teachers, were trained to use the replacement unit on growth patterns and to teach this unit in their classes in the fall of 1991. The $600 000 cost for the first year of this project was funded through federal Eisenhower Program funds that are at the disposal of the state's Director of Mathematics. In future years, school districts will have to pay more of the cost by providing $4 000 in cash toward operating the program.

Pairs of teachers from the 78 middle schools were the primary target audience for the 1991-1992 school year. In the summer of 1992, this group was expanded to include other teachers of mathematics from these schools. The hope is that a majority of members in the mathematics department at each of the schools will participate, bringing the total number of teachers to around 300. During the summer, 11 four-week school academies were conducted. Middle-grades students were available so that the teachers who attended were able to conduct actual classes in the mornings. In the afternoons, the teachers discussed their teaching experience for that morning and were briefed on what will be taught the next day. The replacement units constitute the curriculum in the selected middle schools and are used to demonstrate new approaches to teaching.

The Middle Grades Mathematics Renaissance Project is regarded as a substantive approach that will effect change in the present and the future. The Department does not consider the project an experiment, but a major implementation strategy. Although the curriculum framework has been central to any change for the past 30 years, the 1991 *Mathematics Framework* will be the last. In place of devoting three or four years to developing a curriculum framework, the Department will turn toward the professional development of teachers and school-based change. This shift in direction is a result of the Department's recognition that it has had very little impact on changing what is taught in schools by prescribing, for schools and teachers, what is needed. The Department is now taking a more assertive role in working with teachers and schools to demonstrate the changes needed. As such, the Renaissance Project is the beginning of a new era. The 1990s are viewed by the Department as a time to execute its vision.

REACHING THE CLASSROOM

An extensive study of the impact of the mathematics *Frameworks* and efforts for reforming the mathematics curriculum in California is not available. Some studies and documentation have been conducted that provide insight into how teachers and districts perceive the recommended changes and what steps they have taken to put the new recommendations into practice. Case studies of elementary teachers by researchers from Michigan State University (MSU) reveal that teachers may be aware of the *Framework* but the vision expressed in the *Framework* is not reflected in their teaching. At the secondary level, the 1985 *Framework* has encouraged a certain number of the larger districts to rethink the structure of their curriculum by implementing some version of the Math A, B, and C sequence and to encourage a greater number of students to complete the first year of algebra before graduation.

Elementary Schools

An interesting set of case studies is being conducted by researchers from Michigan State University to study how policy affects practice (Cohen & Ball, 1990). Elementary teachers have been observed and interviewed and their teaching styles analyzed and contrasted with the image conveyed in the 1985 *Mathematics Framework.* The key question is: What have teachers done with the new guidelines and textbooks? Based on the research observations, teachers have responded to the policy recommendations in quite different ways. A second grade teacher of 35 students gave the impression of using many of the recommendations in the *Framework* appropriately -- uses of manipulatives, seeking understanding, and urging her students to apply mathematics to real-world situations. But her actions, such as insisting that students perform a set procedure and structuring lessons for "correct" understanding, defy the intent of the reform recommendations.

> Carol's approach to teaching mathematics includes innovative practices and materials. She uses manipulatives, emphasizes meaning, and wants students to be able to apply mathematics to real-world situations. Consequently, her classroom appears to reflect key dimensions of the *Framework's* vision of practice. Still, her conception of mathematics and her beliefs about knowing and learning mathematics are rooted in the traditional epistemology of school mathematics: Mathematics is a body of knowledge, consisting of concepts and procedures. Skill with these mathematical procedures is the central goal. (Ball, 1990, pp. 256-257)

Traditionally, the textbook was considered the main instrument for communicating the basic ideas of the *Framework*. Adopted by the district from the state's approved list, the textbook Carol used affirmed many of her practices such as using manipulatives and teaching for understanding. She had no real reason to change her view that understanding and engagement are occurring when students are paying attention. This view is contrary, however, to what is portrayed in the 1985 *Framework*. This document describes students' thinking as engaged by teaching "mathematical ideas through posing a problem, setting up a situation, or asking a question. . . . Students need to verify their thinking themselves rather than to depend on an outside authority to tell them if they are right or wrong" (California State Department of Education, 1987, p. 13). Carol remained the authority whose main purpose was to have students learn the procedures and concepts the right way, her way. Imposing meaning on Carol's practice in the context of reform, the case study points to the dilemma that the very mechanism used to transmit the direction of reform is also used to sustain current practices. The research concluded that textbooks are insufficient as a means for conveying the principles of epistemological change being advanced and that policy makers face formidable obstacles in communicating an alternative vision to those who are the implementors.

Other case studies conducted in conjunction with Michigan State University (MSU) project support the finding that the textbook is a major source of instructional guidance for elementary teachers. Dramatic changes in instruction in the spirit of the 1985 *Framework* were difficult to detect. Teachers felt constrained by a number of factors: not having enough time to make changes in their teaching practice; community pressures to teach the traditional way; conflicting messages between instructional approaches as communicated in a textbook and approaches recommended in the *Framework*; lack of knowledge of alternative pedagogical strategies; and competing efforts for reform in the different content areas that elementary teachers are responsible for teaching. Teacher knowledge is a critical factor in reforming classroom practices. Those elementary teachers studied by the MSU researchers reinforce this notion, as well as the insufficiency of a *Framework* or an assessment instrument to overcome the pedagogical practices teachers have been using for years. Those at the state level are aware of this difficulty. The California Mathematics Projects and the Middle Grades Mathematics Renaissance Project are attempts to expand teacher knowledge.

Secondary Classrooms

Districts wanting to effect change in the secondary mathematics classrooms--at the middle grades and high school levels -- faced limited resources. The 1985 *Framework* called for teachers to make full use of calculators and computers, to involve students in active learning, to explain the relationship between what was being studied and what had been learned in the past, and to motivate students. However, some of the larger districts were experiencing shortages in qualified mathematics teachers, limited staff development time, and a large influx of students from minority cultures. A survey conducted by the teachers' union in San Francisco in 1987-88 indicated that 30 per cent of the mathematics sections in the district were being taught by teachers who did not have either a mathematics major or minor. In 1989-90, 15 per cent of the 800 high school mathematics teachers in the Los Angeles Unified School District were teaching with a short-term emergency certificate.

Districts were influenced by the 1985 *Framework* and did take some action, more toward restructuring district mathematics programs than changing classroom practices. Teachers in San Francisco worked on defining Math A and Math B courses. Some teachers piloted materials for these courses, but had difficulty in obtaining the manipulatives needed so that students could become more active in their own learning. Ultimately, Math A and Math B courses came into being and are currently taught with a heavy dependence on materials produced with the support of the State Department of Education.

San Diego Unified School District and Los Angeles Unified School District took initiative in eliminating all general mathematics courses and replacing them by variations of the first year of algebra. The design stipulated that most students take a year of algebra during Grade 9. Grade 9 students who did not meet the prerequisites for this one-year course enrolled in an algebra course that extended over two years. In Los Angeles, the two-year algebra course is regarded as representing Math A as specified in the 1985 *Framework*. The expectation is to accelerate the Los Angeles mathematics curriculum in Grade 5 so that as many students as possible would be able to complete a prealgebra course in Grade 8. The two-year algebra course over Grades 9 and 10 will be for those having greater difficulty. This plan coincided with the district's effort to move from a skill-based curriculum to a more concept-based curriculum. Districts were still working on their approach to Math A and B in 1991 when the draft of the new 1991 *Framework* was released.

Districts and others have been influenced by the *Framework* in structuring their teacher inservices. In 1989-90, San Francisco mathematics teachers could attend a series of programs on mathematics reform as recommended in the 1985 *Framework* and the NCTM *Curriculum and Evaluation Standards* (1989). These programs were sponsored by the San Francisco Urban Mathematics Collaborative. A spring conference was held at which teachers made presentations for other teachers based on recommendations from these reform documents. The *Framework* provided a structure for the Los Angeles urban collaborative in offering workshops to teachers throughout Los Angeles County. Topics at the workshops included quantitative literacy, alternative approaches to teaching algebra, using manipulatives in teaching geometry, using technology, and mathematical modeling. The San Diego Unified School District mathematics supervisor in 1989-90 was reviewing test situations and items as a prelude to developing a test that will conform more to the recommendations in the *Framework*. These districts' efforts also reflect those of the California Mathematics Council. The fall conference of the Southern Section of the California Mathematics Council, held November 17-18, 1989, in Long Beach, focused on the theme, "Building on the *Framework*."

Along with some elementary teachers, the spirit of the 1985 *Framework* was at least reaching a number of the secondary teachers in the large school districts in the state. Teachers were making changes in their classrooms by incorporating technology, encouraging students in mathematics activities, and broadening the curriculum to include some discrete mathematics and more data analysis. Teachers still felt pressure to conform to existing textbooks and lacked the time to make significant curriculum changes. The 1985 *Framework* had caught the attention of teachers, but the momentum for reform had not increased enough or reached a critical mass of teachers to the extent that significant reform in teaching practices in secondary mathematics was apparent in 1991.

QUESTIONS FOR FUTURE RESEARCH

Mathematics education reform in California is in constant flux. As the 1990s begin, an infrastructure appears to be in place for creating systemic change. As time passes, certain questions on mathematics education reform remain:

1. How do the reform recommendations reach classroom teachers? What access do teachers have to the *Mathematics Framework*?

2. What are the barriers to change that are imposed by the California system that work against the reform efforts (i.e., finance structure, reform efforts in different content areas which make excessive demands on teachers' time, and the organization of schools)?

3. How have textbook publishers responded to the recommended changes and what are reasonable expectations of them in contributing to reform?

4. How do systemic change efforts in mathematics education resolve the tension between meeting the need for quality mathematics courses that all students can complete in four years and meeting the needs of students seeking more advanced levels of mathematics in preparation for higher education?

5. How do the efforts for mathematics education reform relate to the magnitude of the challenge of reaching over 5 million students?

6. What has been the impact of federal funds on reform efforts in California and how have these funds been used for professional development?

SOURCES OF INFORMATION

Information for this case study was collected from each of the existing *Mathematics Frameworks*. Interviews were conducted with Dr. Joan Akers, mathematics consultant for the California State Department of Education; Dr. Phil Daro, director of the California Mathematics Projects; Dr. Walter Denham, director of mathematics for the California State Department of Education; Robert Hamada, mathematics supervisor for the Los Angeles Unified School District and current president of the California Mathematics Council; and John Webb, research analyst for Orange County. In addition, information was obtained on schools in San Francisco, Los Angeles, and San Diego from reports and interviews conducted for documenting the Ford Foundation's Urban Mathematics Collaborative Project by the Documentation Project, Wisconsin Center for Education Research, Madison.

REFERENCES

Ball, D. L. (1990). Reflections and Deflections of Policy: The Case of Carol Turner. *Educational Evaluation and Policy Analysis, 12*(3), 247-259.

California State Department of Education. (1963, December). *Summary of the report of the Advisory Committee on Mathematics to the California State Curriculum Commission: The strands of mathematics, mathematics program for teachers, A study of new programs and supplementary materials.* Sacramento: Author.

California State Department of Education. (1972). *The second strands report, mathematics framework, California Public Schools, kindergarten through grade eight.* Sacramento: Author.

California State Department of Education. (1975). *Mathematics framework for California public schools, kindergarten through grade twelve.* Sacramento: Author.

California State Department of Education. (1980). *Proficiency assessment in California: 1980 status report on implementation of California's Pupil Proficiency Law.* Sacramento: Author.

California State Department of Education. (1982*a*). *Mathematics framework and the 1980 addendum for California public schools, kindergarten through grade twelve.* Sacramento: Author.

California State Department of Education. (1982*b*). *Guidelines for proficiency tests.* Sacramento: Author.

California State Department of Education. (1985). *Mathematics framework for California public schools, kindergarten through grade twelve* and *Model curriculum standards, grades nine through twelve.* Sacramento: Author.

California State Department of Education. (1987). *Mathematics model curriculum guide, kindergarten through grade eight.* Sacramento: Author.

California State Department of Education. (1989). *A question of thinking, A first look at students' performance on open-ended questions in mathematics.* Sacramento: Author.

California State Department of Education. (1991*a*). *Mathematics Framework for California public schools, kindergarten through grade twelve,* (Preview edition). Sacramento: Author.

California State Department of Public Instruction. (1991*b*). *A sampler of mathematics assessment.* Sacramento: Author.

Cohen, D. K., & Ball, D. L. (1990). Policy and Practice: An Overview. *Educational Evaluation and Policy Analysis, 12*(3), 233-239.

Kansas State Board of Education. (1991). *Kansas Mathematics Standards, 1991 Kansas Statewide Pilot Assessment Results.* Topeka, Kansas State Board of Education, September.

National Council on Measurement in Education. (1992). *NCME Newsletter*. Washington, D.C.: Author, *1* (1), January.

National Council of Teachers of Mathematics. (1980). *An agenda for action: Recommendations for school mathematics of the 1980s*. Reston, Va: Author.

National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics*. Reston, VA: Author.

National Council of Teachers of Mathematics. (1991). *Professional standards for teaching mathematics*. Reston, VA: Author.

National Research Council. (1990). *Everybody counts: A report to the nation on the future of mathematics education*. Washington, D. C.: National Academy Press, 1990.

Pandey, T. (1992). Test development profile of a state-mandated large-scale assessment instrument in mathematics. In T. A. Romberg (Ed.), *Mathematics Assessment and Evaluation*. Albany, NY: State University of New York Press.

ANNEX A

Chronology

1963 The Strands of Mathematics. In the *Bulletin of the California State Department of Education, 23*, No. 6, December, 1963.

1972 California State Department of Education. *The Second Strands Report, Mathematics Framework, California Public Schools, Kindergarten Through Grade Eight.* Sacramento: California State Department of Education.

1974 California State Department of Education. *Mathematics Framework for California Public Schools, Kindergarten Through Grade Twelve.* Sacramento: California State Department of Education.

1976 Legislation establishing the first California Assessment Program (CAP).

1982 California State Department of Education. *Mathematics Framework and the 1980 Addendum for California Public Schools, Kindergarten Through Grade Twelve.* Sacramento: California State Department of Education. [Note: An addendum placing problem solving as an umbrella over all of the strands was written in 1980.]

1982 California Pupil Proficiency Law (Education Code sections 51215-51218) requiring all students to demonstrate proficiency in the basic skills prior to graduation from high school.

1983 California Mathematics Projects Initiated (1983).

1985 California State Department of Education. *Mathematics Framework for California Public Schools, Kindergarten Through Grade Twelve* and *Model Curriculum Standards. Grades Nine Through Twelve.* Sacramento: California State Department of Education.

1986 Rejection of all K-8 textbook series for not meeting the criteria as specified in the 1985 *Mathematics Framework.*

1987 California State Department of Education. *Mathematics Model Curriculum Guide, Kindergarten Through Grade Eight.* Sacramento: California State Department of Education.

1988 Fall symposium held to bring the textbook publishers into the process of developing the 1991 *Mathematics Framework* at an early stage.

1990 First replacement unit, "Seeing Fractions," was available.

1991 The Middle Grades Mathematics Renaissance Project, school-based change, was initiated.

1991 California State Department of Education. *Mathematics Framework for California Public Schools, Kindergarten through Grade Twelve.* Sacramento: California State Department of Education.

THE ROLE OF THE NATIONAL COUNCIL OF TEACHERS OF MATHEMATICS IN THE CURRENT REFORM MOVEMENT IN SCHOOL MATHEMATICS IN THE UNITED STATES OF AMERICA

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INTRODUCTION

A "reform movement" in school mathematics in the United States is now underway. Awareness of the need to change school mathematics is not new. For at least the last 25 years (e.g., College Entrance Examination Board, 1959; Fehr & Hunt, 1961; *Goals for School Mathematics*, 1963) those responsible for mathematical education have attempted to reshape and improve the school mathematics curriculum. Activities in Western nations that have focused on improving mathematics education have ranged from international conferences and assessments to curricular experiments (Howson, Keitel, & Kilpatrick, 1981) and national investigations (e.g., Committee of Inquiry into the Teaching of Mathematics in the Schools [CITMS], 1982; National Advisory Committee on Mathematical Education [NACOME], 1975; Mathematical Sciences Education Board, 1989). But today in the United States, there are two important differences between past activities, which were directed by governmental agencies (federal, state, or local), commercial firms (publishers, workshop entrepreneurs), or specific interest groups (mathematicians), and current activities. The differences are:

1. Leadership for the reform activities has been assumed by professional organizations, and

2. Consensus has been reached among these organizations about the direction and the form the needed changes must take.

The impetus for the current reform activities was the publication of two reports in 1983: *A Nation at Risk* (National Commission on Excellence in Education) and *Educating Americans for the 21st Century* (National Science Board Commission on Precollege Education in Mathematics, Science, and Technology). The basic argument in both documents was that this nation's mathematical and scientific understanding did not match its current or future needs, and both called for radical changes in school mathematics and school science. Reactions to these reports by professionals in the mathematical sciences were presented in *New Goals for Mathematical Sciences Education* (Conference Board of the Mathematical Sciences, 1984) and *School Mathematics: Options for the 1990s* (Romberg, 1984). Each of these responses was the consequence of a meeting called by professional organizations. The first document was the result of a meeting of the leaders in the mathematics community under the auspices of the Conference Board of the Mathematical Sciences (the presidents of all of the professional mathematical sciences organizations), and the second report came out of a meeting of leaders in the mathematics education community organized by the National Council of Teachers of Mathematics. The participants of both conferences made a series of very similar recommendations about the nature of needed changes. However, what was new was that to accompany each recommendation a strategy was proposed for accomplishing the changes -- a strategy that involved activities to be initiated and directed by the professional organizations. The ten recommendations presented in *School Mathematics: Options for the 1990s* were:

1. A task force should be organized to propose guidelines for a K-8 mathematics curriculum.

2. A task force should be organized to propose guidelines for a 7-14 mathematics curriculum.

3. A task force should be organized to propose standards for computer courseware so that they are compatible with the curriculum guidelines.
4. In elementary schools, specialist teachers of mathematics should teach all mathematics beginning no later than grade 4 and supervise mathematics instruction at earlier grade levels.

5. In secondary schools, master teachers of mathematics should teach or supervise all mathematics instruction.

6. A task force should be convened to propose certification standards for both elementary school specialist teachers of mathematics and secondary school master teachers of mathematics.

7. A task force should be convened to prepare model programs for the preservice and inservice education of all mathematics teachers, K-12.

8. Research on the learning and teaching of mathematics should be actively encouraged, and research-based knowledge incorporated into recommended guidelines and standards.

9. In each school or school district, a school mathematics committee should use the curriculum guidelines and staffing recommendations to outline the curriculum and provide support for the mathematics program.

10. Professional organizations concerned with mathematics education should establish a permanent national steering committee for mathematics education to survey efforts of federal, state, and local agencies to reform school mathematics and to report on the progress of the reform effort.

Note that each recommendation was directed to persons or groups. Now, some eight years later, it is apparent that the work done has addressed all ten recommendations. For example, in 1985, the Conference Board of the Mathematical Sciences organized the Mathematical Sciences Education Board under the National Research Council of the National Academy of Sciences in response to Recommendation 10; in 1987, the U.S. Department of Education funded, for the first time, a national research center on the teaching and learning of mathematics in response to Recommendation 8; and in 1991, the Mathematical Association of America published *A Call for Change*, which outlines a radical preservice education program for mathematics teachers, K-12, in response to Recommendation 7. In particular, this last document demands that collegiate mathematics be taught differently so that prospective teachers learn what it means to *do* mathematics, rather than to absorb the mathematics developed by others.

THE NATIONAL COUNCIL OF TEACHERS OF MATHEMATICS

The most ambitious example of responding to the reform recommendations was carried out by the National Council of Teachers of Mathematics (NCTM) in relationship to Recommendations 1 and 2. NCTM is an organization of nearly 100 000 teachers of mathematics, mathematics educators, and mathematicians. Under the leadership of two of its presidents, Joseph Crosswhite and John Dossey, the organization decided to take a proactive role in the reform efforts. Utilizing its own resources in 1986, NCTM organized the Commission of Standards for School Mathematics and, in 1989, published *Curriculum and Evaluation Standards for School Mathematics* (hereafter called the *Standards*). This 258-page document presents a vision of a mathematics program for Grades K-12 that responds to the concerns raised about the mathematical needs of our society for the 21st Century. An overview of the *Standards* is included in this document (Appendix A). To understand the organization's perspective about curriculum reform, the assumptions upon which the *Standards* are based are summarized.

The *Standards* were drafted during the summer of 1987 and revised during the summer of 1988 by the members of four working groups, each representing a cross-section of mathematics educators, including classroom teachers, supervisors, educational researchers, teacher educators, and university mathematicians. Six members served on each working group. They were appointed by John Dossey, president of NCTM. Their work was authorized and reviewed by the NCTM Commission on Standards for School Mathematics, and coordinated by Thomas A. Romberg, who was assisted by E. Anne Zarinnia. The working groups met during the summer of 1987 for two-week writing sessions and in the summer of 1988 for one two-week writing session.

A draft of the 1987 version of the *Standards* was sent to each member of NCTM. During the 1987-1988 school year, individuals, organizations, and groups of teachers took advantage of the opportunity to react to the document and submitted their suggestions. Over 1 000 comments were received. The revisions were based on these copious and helpful reactions to the document's working draft. The final document was considerably strengthened and made more coherent because of the careful reviews and thoughtful suggestions that were provided. The writers and NCTM were confident as the document evolved that it represented the consensus of NCTM's members regarding the fundamental content that should be included in the school mathematics curriculum and key issues concerning the organization and implementation of student and program evaluation. The value of the NCTM *Standards* rests in the process used to create the *Standards* and to form a broad consensus for their support. NCTM continued consensus building after the publication of the *Standards* by working with MSEB to gain support from a number of organizations.

The Curriculum as an Instrument of Change

A traditional assumption in education is that changing curricula is the easiest way to change school practices. However, curriculum development is more than a change in method or content; it is an effort to change the culture of schools and may involve different levels of restructuring. Ameliorative change may typically involve changing one small part of the system, such as the current textbook, but it does not challenge values or traditions. Typically, change that does challenge basic values and traditions is nominal. If there is actual change, it is more frequently mechanical or illusory than real; patterns of adoption range from labels and procedures to complete surface trappings. But change can only be considered real if new values and principles also are adopted. Actual, substantive change disrupts old habits and beliefs, usually evoking resistance. Therefore, the first step toward increasing the likelihood of constructive curricular change is identification of the traditions and values being challenged (Romberg & Price, 1983).

The most deep-seated traditions and values are personal, in that they are rooted in each individual's beliefs about the world. In any significant effort, people tend to be goal directed; they work best toward new goals if those goals are personal. They may appreciate the need for change, but formulate inappropriate goals, unless their own model of the world matches reality. For the past hundred years, Western society has been dominated by the machine, the factory, rationalism, analytic thought, experimental science, and the technology of paper. These, as metaphor and model, prompted the development of scientific management and behaviorism (Kilpatrick, 1979). This sequence led directly to what Howson, Keitel, and Kilpatrick (1981) refer to as the "taylorization" of school mathematics, which was seen as the most pressing problem facing the reform of mathematical education. As long as the sequence remained unrecognized, unchallenged, and unchanged, it would continue as a source of intellectual incoherence, impeding progress towards the development of new goals. Tradition ensures that people's belief structures and work habits will not be easily changed. If mental models remain the same, even when the intent to change exists, real change may not be effected, despite the illusion of change that has been systematically created.

The *Standards* were developed to challenge these traditions. New perspectives on school practices were explored in considering the direction of desirable change in mathematics education with respect to knowledge, the work of students and teachers, and the professional nature of the teaching enterprise.

Knowledge

One of the intentions of mathematical education is to ensure that students acquire mathematical knowledge, preferably as a communally accepted structure. However, because the content of school mathematics is necessarily restricted, only some mathematical ideas can be taught. Mathematics as a school subject has been organized by topics -- arithmetic, algebra, geometry, and so forth--rather than by what mathematicians do -- study patterns, make conjectures, build models, find solutions, construct proofs, and so on. It is this difference that is at the root of the controversy between mathematics as a science and mathematics as a school subject.

The emphasis in the reform view of mathematics stresses creativity, innovation, problem solving, and a generally high level of "at-homeness" (CITMS, 1982, p. 11) with mathematics. Integrative, intuitive thinking is seen as essential to the process. In sum, creativity and innovation are integral to both the formation of new knowledge and to solving problems, which could be described as applied knowledge creation. Thus, this emphasis suggests that school mathematics is, or derives from, a philosophy, based on a model of mathematicians doing mathematics. Hence, knowing and doing mathematics, as opposed to knowing about mathematics, is an important part of major current statements of purpose.

When mathematical knowledge means knowing and doing mathematics rather than knowing about mathematics, other things follow. Knowledge is personal and communal in that, while it may originate with an individual, it is validated by the community. Thus, the process of adding to mathematical knowledge through communication is an integral part of knowing mathematics. Furthermore, the criterion for knowledge is not necessarily that it be true, but that the means for elaborating knowledge be incorporated into the general system of learning. (Rescher, 1979). In a sense, adding to the emphasis structure of mathematical knowledge *is* mathematics. This view means that mathematics is, by definition, dynamic and constantly changing; it is not, as has been the case in schools, a static, bound accumulation of facts or methods. The implications of these views for the school mathematics culture are extensive, suggesting radical change in the work of students and teachers and in the professional responsibilities of all educators.

The Work of Students

The roles and, therefore, the work of teachers and students are complementary (Skemp, 1979); one group teaches, the other learns. However, schools are ostensibly places where students gather to learn; thus, the role of the teacher should complement that of the student, rather than vice versa. Unfortunately, when knowledge is regarded as *knowing about* rather than *knowing*, the vocabulary reflects a reversal of emphasis: the work of the teacher is to "transmit" knowledge. Logically, this means that the student's job is to receive knowledge and to regurgitate it on demand. In fact, the real work of the student is often a matter of negative goals, meeting expectations sufficiently to pass through the system (Skemp, 1979).

If students are to create mathematical knowledge, as is argued in the *Standards*, both the kinds of new knowledge and the work involved in its creation must be considered. Knowledge may be new to the individual student, or it may be new to the global community. Another type of new "knowledge" is that generated by the successful application of mathematics to problems, each instance of which either revalidates existing knowledge or prompts efforts to expand the domain (Jaffe, 1984). This suggests for students a process of continually expanding and applying the system of personal knowledge and validating it against the domain as a whole.

Briefly, then, students' work consists of extending the structure of the mathematics that they know, by making, testing, and validating conjectures that may originate as postulates of conscious thought or that may be derived intuitively. As long as students are making the conjectures, their mathematical knowledge will be structured, consciously or unconsciously, because conjectures cannot be created from nothing. Their conjectures may be abstract or applied; the modeling involved in the latter both tests a conjecture and develops a sense of consequence. This models the process of reflective intelligence in which the structure of knowledge is constantly revised by reflecting on events, seeking ways to fit them into the existing structure, and testing the structure's predictive powers.

Verbal and written communication is a crucial part of the process for several reasons. First, logical argument is central to mathematical proof. Second, communication of that proof is the means by which personal knowledge is submitted for systematizing into the domain of mathematical knowledge and thus accepted as new knowledge (Rescher, 1979). Third, developing competence in the categories and structures of the language system structures the child's understanding and advances it toward a public mode of consciousness (Russell, 1978).

The work of students is not a matter of memorization, nor of following algorithms, even though these play a part. The creation of knowledge, whether at the personal or global level, involves a constant process of deliberately moving beyond what is known into the realm of disorganization, repeatedly guessing at connections and mental models until new and definable structures, objects, relationships, and processes emerge. It is important to note that this is not the same as the kind of discovery learning that anticipates the acquisition of particular knowledge through discovery rather than via exposition. It requires creativity, fluent verbal and written communication, and constructive, critical thinking.

The Work of Teachers

If one regards the roles and work of students and of the teacher as complementary, and if the emphasis is on creating knowledge rather than on absorbing the history of other people's knowledge, then the teacher's work is to support, promote, encourage, and facilitate the creation of knowledge by students. In order to know, students must educate themselves. In flight training, for example, where knowing can make the difference between life and death, the intrinsic motivation that ensures that the student will take responsibility for his/her own learning is crucial (unless one regards death as an extrinsic motivation). Thus, according to Dawson (1983), "The teacher and the content are not paramount: THE LEARNER IS" (p. 592). This suggests that the essential work of teachers includes:

1. Ensuring successful experience for children:

2. Providing for extended and cooperative project work, whose final product is a report;

3. Bringing an informal and interdisciplinary approach to mathematics;

4. Encouraging verbal and written eloquence in arguing intuitions;

5. Encouraging self-evaluation and providing for group evaluation of new knowledge and reference to the formal domain;

6. Demonstrably exercising intuition and adding to students' own personal knowledge;

7. Providing an emotional and physical environment supportive of student work. This includes, for example, recognition of the need for cessation of conscious effort or a change of activity, or of an urgency to immediately capture a thought on paper. It also includes providing for student experience with both physical and intellectual modeling.

8. Changing from structural authority based on negative or extrinsic goals of students to sapiental authority (Skemp, 1979) founded on intrinsic goals. This involves moving from regimented uniformity to individual and collaborative creativity.

9. Monitoring the structure of knowledge being created by the child; and

10. Using technology appropriately in intuition, play, the acquisition and manipulation of information, logical argument and communication, in evaluating new knowledge against the domain, and in tracing the development of the student's network of knowledge.

In short, it is essential that the teacher provide the environment for learning, act as a mentor, and then get out of the way.

The Professionalism of Teachers

The legitimacy of schooling is derived from the professional status of teachers (Popkewitz, Tabachnick, & Wehlage, 1982), which vests them with the authority to mold children and bestow a "social identity" that frequently impacts their entire adult life. A profession is recognized because it has specialized knowledge, a corporate bond that supports the development of collective wisdom, and sovereignty in its field (Otte, 1979).

If the role of teachers is to support the creation of mathematical knowledge by students, the professionalism of teachers should support and enhance their role. In fact, if belonging to a profession fosters specialized knowledge, collegiality, collective wisdom, and sovereignty in the field, membership endows teachers with sapiental authority. This suggests that if teachers do not have the attributes of professionals, they either are not members of a profession, or the profession itself is deficient.

Approached from a different point of view, the professional backing needed by teachers is that which would:

1. Ensure excellent preservice and inservice education, congruent in style with the quality of teaching expected;

2. Provide for teachers to constantly expand their own knowledge of the domain through such things as sabbaticals, summer scholarships for foreign study, inservice, and computer conferencing with experts -- placing no restrictions on the directions of investigation;

3. Provide for constant electronic collegiality;

4. Educate the entire system of education to support the efforts of the teacher, including superintendents, boards, professional bodies, and parents;

5. Provide a framework for rigorous self-regulation; and

6. Abolish the intolerable constraints under which they now operate; namely, standardized testing, standardized texts, and the cover-the-ground philosophy.

The *Standards* present a vision of school mathematics based on the principles evoked in these five sections on curriculum, knowledge, the work of students, and the work and professionalism of teachers. They represent NCTM's attention in its reform efforts to coherence of purpose, tools, action, and knowledge. Furthermore, the *Standards* argue for a service concept of education, with children as the recipients.

THE NCTM *CURRICULUM AND EVALUATION STANDARDS FOR SCHOOL MATHEMATICS*

Critical to the need for new standards for school mathematics is the realization that mathematics is changing and that what people need to know about mathematics to be productive citizens is changing. Important factors implicated in these changes are the advances in technology, such as the prevalence of computers and calculators and the expanding use of quantitative methods in almost all intellectual disciplines. In defining what mathematics is needed, five goals are identified by the *Standards* for the K-12 curriculum.

Students are to develop their mathematical power and become mathematically literate by:

1) Learning to value mathematics;
2) Becoming confident in one's own ability;
3) Becoming a mathematical problem solver;
4) Learning to communicate mathematically; and
5) Learning to reason mathematically.

There are four common standards, based on these goals, that are part of each set of standards for each grade grouping: mathematics as problem solving, mathematics as communication, mathematics as reasoning, and mathematical connections. Positioning these standards as the first four of each set attests to their importance and their relevance to all instruction. Although not stated directly as standards, the valuing of mathematics and confidence in doing mathematics are emphasized throughout the descriptions in the *Standards* and the suggested approaches to teaching. Focusing on problem solving, communicating, reasoning, and connections as standards for all three grade groupings recognizes that these will be attained over a period of years as a result of their reinforcement both within and across grade levels.

Solving problems, communicating, and reasoning via mathematics are not independent of each other, but develop concurrently through the interaction of each with the other. The development of these mathematical abilities is better viewed as degrees of maturation within each process rather than as attainment at discrete levels. Students come to kindergarten already possessing problem solving strategies for finding answers to problems in familiar situations, words for describing situations, and forms of thinking about situations. Over the school years, through additional experiences, these strategies can be further developed, new strategies learned, and more sophisticated problems solved. The intent of the NCTM *Standards* is for the mathematics curriculum to become the means for expanding students' existing knowledge; for introducing students to additional forms of mathematical thought; and for developing their power to use mathematics as a means of abstracting the world, interpreting the world, working within the world, and increasing their knowledge of the world.

The Curriculum Standards

The approach taken and the topics covered within each grade category of the *Standards* varies and is affected by the developmental level of students and the inherent structure of mathematics. In Grades K-4, the empirical language of the mathematics of whole numbers, common fractions, and descriptive geometry, derived from the child's environment, should be emphasized. In these grades, a foundation for all further study of mathematics is firmly established. Mastery of computational algorithms has generally been considered a primary objective in the current curriculum for the lower grades. Skill and proficiency in calculating by using paper-and-pencil algorithms are important indicators of success in the curriculum. The emphasis in the *Standards*, on the other hand, is on the fact that the use of paper-and-pencil algorithms is only one among several forms of computing. Indeed, depending upon the problem situation in which a computational answer is sought, one may need to estimate an answer or find an exact answer. If the latter, then one again has choices, depending on the content. One choice is to calculate mentally, a second is to use a paper-and-pencil algorithm, and another is to use a calculator. Thus, students need to learn *all* computational procedures -- estimation, mental arithmetic, paper-and-pencil algorithms, and calculator uses. It is *as* important to be able to *choose among different means of computation* as it is to achieve appropriate answers.

Along with using number to describe the world empirically, it is necessary in the lower grades to develop a sense of space and knowledge of the basic concepts and rules for building geometries. Also, the underpinnings of the descriptive and inferential sciences of statistics and functions that will be developed in later grades need to be introduced and experienced in Grades K-4. Throughout the process, the learning of mathematics should involve exploring, validating, representing, solving, constructing, discussing, using, investigating, describing, developing, and predicting.

In contrast to the more traditional view of the K-4 curriculum as developing the computational skills with the four operations, the *Standards* portray the early years as laying the foundation for a rich and broad school mathematics curriculum. The *Standards* recommend a decreased emphasis on complex paper-and-pencil computations, the isolated treatment of computation facts, and rote memorization. The *Standards* do recommend an increased emphasis in having students work with patterns and relations, solving everyday problems, gaining number sense, and expanding students' spatial sense.

In the Grades 5-8, according to the *Standards*, the empirical study of mathematics should be extended to include other numbers beyond whole numbers and emphasis should gradually shift to developing the abstract language of mathematics needed for algebra and more formal mathematics. The middle grades are not viewed as the culmination of the arithmetic curriculum, but are seen as a transition leading to more advanced mathematics. In this sense, the number of topics covered by all students should be increased to include significant work in geometry, statistics, probability, and algebra. The study of arithmetic skills should not be carried out in isolation, but should be driven by subject matter provided in these other areas. Work in the middle grades should lead students to think quantitatively as well as spatially. There should be an increasing understanding of mathematical structure so that students become more aware of the relationships within and among operations, numbers, spatial figures, and other forms of representation.

Rather than a culmination of developing computational skills, the more traditional view for the middle grades, the 5-8 Standards stress the importance of viewing the middle grade's mathematics program as a transition. The mathematical experiences students have in Grades 5-8 should advance their knowledge and interest in mathematics from number and spatial sense to the use of symbols and abstractions. Rather than memorizing formulas, practicing tedious paper-and-pencil computations, and doing worksheets, middle grade students are to begin applying mathematical ideas and methods to help give them a greater understanding of their world, to pursue open-ended problems, to discuss mathematical ideas, and to employ a variety of different mathematical representations. Algebraic ideas of variables, expressions, and equations should be spread across the middle grades rather than reserved for advanced students in Grade 8 or the beginning of the secondary mathematics experience.

In high school, Grades 9-12, students are assumed to have had the mathematical experiences of a broad, rich curriculum and to have reached some degree of computational proficiency. The emphasis of the curriculum for these later grades should be shifted from paper-and-pencil procedural skills to conceptual understanding, multiple representations and connections, mathematical modeling, and mathematical problem solving. In the pursuit of these objectives, lessons should be designed around problem situations posed in an environment that encourages students to explore, to formulate and test conjectures, to prove generalizations, and to communicate and apply the results of their investigations. An important goal for high school students is that they become increasingly self-directed learners through experience in instructional programs designed to foster intellectual curiosity and independence. Although there should be variation in the depth and breadth of coverage, all students taking at least three years of high school mathematics should be exposed to algebra, functions, geometry, trigonometry, statistics, probability, discrete mathematics, the conceptual underpinnings of calculus, and mathematical structure. Throughout the curriculum, as these topics are integrated across courses, students should become aware of the structure of mathematics and be able to recognize and make the connections among topics. These connections include forming mathematical representations of problem situations and the ability to distinguish among equivalent forms of representations.

Traditionally, the high school curriculum has been segmented into topical mathematics courses--Algebra I, Geometry, Algebra II, and Trigonometry to name a few. High school students progress through these courses guided by expectations of continuing in higher education. Many universities and colleges require the successful completion of at least two years of mathematics including Algebra I and Geometry. The 9-12 *Standards* present a strong statement that all students, whatever their future plans, should have three years of high school mathematics. All students should take a core curriculum that is not differentiated by topics, but differentiated by the depth to which a topic is studied and the degree of formalism. Along with this structural change from a basic to a core curriculum, the *Standards* require less rote memorization of facts, less recourse to teacher and text as exclusive sources of knowledge, and a reduction in teacher exposition. What is recommended is a greater use of a variety of instructional formats, of technology, and of an active involvement of students in constructing and applying mathematical ideas.

Evaluation Standards and Assessing Mathematics

The fourteen NCTM Evaluation Standards are divided into three groups. In one group are the seven student assessment standards that describe what is to be observed and measured in the process of determining what mathematics the students know. These state that in order to adequately test mathematical knowledge, assessment needs to measure knowledge of mathematics as an integrated whole, conceptual understanding, procedural knowledge, problem solving, reasoning, communication, and mathematical disposition. A second group is comprised of three general assessment standards that present principles for judging assessment instruments. Inherent in the general assessment standards is an assumption that all evaluation processes should use multiple assessment techniques that are aligned with the curriculum and consider the purpose for assessment. A third group is comprised of the four standards that identify what should be included in evaluating a mathematics program. One purpose for program evaluation is to obtain relevant and useful information for making decisions about curriculum and instruction. These four evaluation standards provide: indicators of a mathematics program consistent with the Curriculum

Standards; the focus for examining the instructional resources of a mathematics curriculum; the focus for examining instruction and its environment to determine a mathematics program's consistency with the Curriculum Standards; and provisions for program evaluation, to be planned and conducted by an evaluation team.

IMPACT OF THE *STANDARDS*

The NCTM *Curriculum and Evaluation Standards for School Mathematics* are significantly influencing the mathematics curriculum reform in the nation. The full impact of this document and the efforts surrounding it are only now, however, becoming fully apparent. The *Standards* have reached a wide professional audience and have begun to gain the attention of those who are in the highest branches of the government. Even though the *Standards* were written, produced, and distributed by a professional organization that lacked formal authority over any aspect of education in the country, they are being used by local, state, and national agencies as models for what should be included in the curriculum and what mathematics K-12 students, should know. In addition to having a national influence, NCTM has experienced a growth in membership in recent years that can be at attributed, in part, to its active involvement in advancing reform in mathematics education.

Growth of NCTM

In 1983, membership of NCTM had reached 55 000 members, its lowest level since 1963. For the past eight years, its membership has steadily increased to a total of 93 192 by the end of 1991. The membership includes both individual and institution members. Nearly half of this eight-year growth has come since the release of the *Curriculum and Evaluation Standards* in 1989. As a result of this increase in membership, the organization is reaching more teachers and schools throughout the U.S. and Canada. Readership of its publications has increased and a larger number of people are attending its annual meeting, the seven or eight yearly regional meetings, and meetings of its local affiliates.

Influence on States

The NCTM *Standards* are beginning to take hold in states and becoming central to curriculum and assessment directives. The 1991 *Mathematics Framework for California Public Schools* (California Board of Education, 1991) affirms the *Standards* as defining the direction that state has been taking for some time. California's *Framework* builds upon the *Standards*, using many of the major themes. "In keeping with the national consensus, this Framework incorporates these NCTM standards as desired outcomes of the K-12 curriculum. The strands used in the current Framework correspond closely to many of the individual NCTM Standards, while the unifying ideas used in the current Framework represent themes that appear in several different strands (and standards)" (California Board of Education, 1991, p. 6). The California Assessment Program centers its assessments on the *Framework* and seeks to measure mathematical power as described in that document and the *Standards*.

Those in other states have attested to the relationship of the NCTM *Curriculum and Evaluation Standards* to their assessment programs (NCTM, 1992). The Kansas State Board of Education has implemented a state-wide test based on the *Standards*. Student performance is assessed in areas of knowledge base, mathematics reasoning, routine and nonroutine problem solving, communications, and mathematics concepts and procedures. Vermont is experimenting with a state-wide assessment project using portfolios in Grades 4 and 8. The *Standards* helped to establish the criteria being used in problem solving and communication and provide guidance in considering factors such as risk-taking, evidence of group work, and other empowerment qualities. Some states were engaged in on-going assessment projects at the time the *Standards* were released. Texas has made some revision in its state-wide testing based on the *Standards* and is considering the possibility of other forms of assessment in addition to paper-and-pencil multiple-choice testing. A committee composed of citizens from the state of Michigan has worked five years in developing a new state-wide mathematics test. Members of this group are very active in NCTM and have brought their familiarity with the *Standards* to bear on their development of a Michigan state assessment test.

National Attention

The NCTM *Standards* have been cited by the new U.S. Secretary of Education, and by state governors, such as Colorado's Governor Roy Romer, as a model for providing leadership in the development of curriculum or change. A National Council on Education Standards and Testing (NCEST) has been created in 1991 to examine the desirability and feasibility of establishing standards and developing a national assessment system. The president of NCTM, Iris Carl, has been appointed to serve on this council. In accepting her appointment Ms. Carl commented, "This appointment speaks to the Secretary of Education recognizing the work of the NCTM, the *Standards*, and the way we have involved our members in making an accurate representation of the mathematics community" (NCTM, 1992, p. 8).

The national attention given the *Standards* has placed the document and the process used to develop the document in an unanticipated role with respect to educators in reform. Educators in other curriculum areas are being pressured by politicians and others to produce a similar resource. The National Academy of Science has been given funds from the National Science Foundation to develop standards for the sciences in Grades K-12. The New Standards Project, in building a new examination system to be used by states, has worked toward specifying content "standards" for language arts that could be used for that assessment development effort. In these and other projects, professionals in other fields are aware of the NCTM *Curriculum Evaluation Standards* and have begun to give serious consideration to developing comparable standards specifying what students should know.

Change in Textbooks

Mathematics instruction in American schools is driven by textbooks, particularly in the elementary grades. Fewer than 10 major publishers are now producing textbook series, K-8, for purchase by school districts. Textbook adoptions generally are for five to seven years. Writing and producing a K-8 textbook series can require an initial investment by a company of $20 million or more. Three years or more are required to write and produce a new series. Then a series is revised a couple of times at two year intervals. The life of a series from its first conceptualization to the point at which a new edition is produced can be 8 to 10 years. Authors have some influence on what will be in a textbook and what format will be used, but the largest influences are the marketplace and the perception of what schools and districts are willing to buy. The state guidelines in California and Texas, both with state-wide textbook adoptions, are widely regarded by publishers as defining the market place and what should be included in textbooks. Because the 1991 California *Framework* coincides with the *Standards*, future textbooks should become more responsive to recommendations and goals defined in the *Standards*.

The release of the *Standards* occurred at a time when many of the mathematics series had introduced new editions in the market place. Revisions have already been made in these textbooks to give an appearance of the language used in the *Standards*, by making the words "problem solving," "reasoning," "communications," and "connections" much more visible to the reader, even though the real substance in the textbooks has not changed greatly. One textbook author of a new K-8 series commented that the publishers have misjudged the speed with which the *Standards* have reached the attention of classroom teachers. That series was already in the process of being written when the *Standards* were released, but a few changes motivated by the new recommendations made their way into the textbook. For example, lessons devoted to long division with a two-digit divisor were reduced in number and only one lesson using a three-digit divisor was included. For this latter lesson, students were instructed to use a calculator. This is a change from previous textbook editions that put greater emphasis on long division with multi-digit divisors. Another apparent influence of the *Standards* was evident in the inclusion of more algebra and data analyses in Grades 6, 7, and 8. Systems of equations are presented in Grade 8. Stem-and-leaf plots and random number tables are used in Grades 7 and 8. The company is now considering an alternative series that would be less textbook based and offer students the challenge of doing more in the spirit of investigating mathematics. This one example indicates that the *Standards* have even reached the attention of publishers whose textbook materials have tended to be the driving force of mathematics instruction in the United States.

SUMMARY

The development of the *Standards* by the National Council of Teachers of Mathematics should be seen as an important intellectual and political undertaking: intellectual, because it was based on evolving concepts of what it means to know mathematics, of the work of students and teachers, and on an expanding perception of the professional responsibilities of the teacher; and political, both because it was developed in response to policy expectations for change, and because it was deliberately constructed to challenge a set of entrenched traditions about school mathematics. Only time can tell whether the current reform efforts in the United States will be successful. However, since the leadership is coming from an organization that represents those who eventually must carry out the changes in content and pedagogy, then, perhaps, real reform will happen -- if those teachers who developed this vision can convince other teachers of its viability.

QUESTIONS FOR FURTHER STUDY

1. What has been the impact of the NCTM *Standards* on teachers, the curriculum, and student learning?

2. How extensive has the dissemination of the *Standards* been?

3. What features of NCTM's strategy to produce the *Standards* worked best, and what features did not work?

4. How has a clearly stated vision been used to generate a climate for the development of other reform efforts?

5. After four years, what are the weak points of the *Standards* and what changes could be made to strengthen the strategy for their dissemination?

REFERENCES

California Board of Education. (1991). *Mathematics framework for California public schools: Kindergarten through grade twelve.* Sacramento: California Board of Education.

College Entrance Examination Board. (1959). *Program for college preparatory mathematics.* New York: Author.

Committee of Inquiry into the Teaching of Mathematics in Schools. (1982). *Mathematics counts (The Cockroft Report).* London: Her Majesty's Stationery Office.

Conference Board of the Mathematical Sciences. (1984). *New goals for mathematical sciences education.* Washington, DC: Author.

Dawson, A. J. (1983). The work of Lakatos and Gattegno: Implications for mathematics teaching. In M. Zweng, T. Green, J. Kilpatrick, H. Pollack, & M. Suydam (Eds.), *Proceedings of the Fourth International Congress on Mathematical Education* (pp. 590-592). Boston: Birkhauser.

Fehr, H. F., & Hunt, L. N. H. (Eds.). (1961). *New thinking in school mathematics.* Paris: Organization for European Economic Cooperation, Office for Scientific and Technical Personnel.

Goals for school mathematics. The report of the Cambridge conference on school mathematics. (1963). New York: Houghton Mifflin.

Howson, G., Keitel, C., & Kilpatrick, J. (1981). *Curriculum development in mathematics.* Cambridge: Cambridge University Press.

Jaffe, A. (1984). Ordering the universe: The role of mathematics. In National Research Council, The Commission on Physical Sciences, Mathematics, and Resources, *Renewing U.S. mathematics: Critical resource for the future. Report of the ad hoc committee on resources for the mathematical sciences* (pp. 117-162). Washington, DC: National Academy Press.

Kilpatrick, J. (1979). Methods and results of evaluation with respect to mathematics teaching. In *New trends in mathematics teaching* (Vol. 4, pp. 162-179). Paris: UNESCO.

Mathematical Association of America. (1991). *Call for change.* Washington, DC: Author.

Mathematical Sciences Education Board. (1989). *Everybody counts.* Washington, DC: National Academy Press.

National Advisory Committee on Mathematical Education. (1975). *Overview and analysis of school mathematics, K-12.* Washington, DC: Conference Board of the Mathematical Sciences.

National Commission on Excellence in Education. (1983). *A nation at risk: The imperative for educational reform.* Washington, DC: U.S. Government Printing Office.

National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics.* Reston, VA: Author.

National Council of Teachers of Mathematics. (1991). *Professional standards for teaching mathematics.* Reston, VA: Author.

National Council of Teachers of Mathematics. (1992, January). *News Bulletin.* Reston, VA: Author.

National Science Board Commission on Precollege Education in Mathematics, Science, and Technology. (1983). *Educating Americans for the 21st century.* Washington, DC: Author.

Otte, M. (1979). The education and professional life of mathematics teachers. In *New trends in mathematics teaching* (Vol., 4, pp. 107-133). Paris: UNESCO.

Popkewitz, T.S., Tabachnick, B.R., & Wehlage, G.G. (1982). *The myth of educational reform: School response to planned educational change.* Madison: University of Wisconsin Press.

Rescher, N. (1979). *Cognitive systemization: A system-theoretic approach to a coherentist theory of knowledge.* Totowa, NJ. Rowman and Littlefield.

Romberg, T.A. (1984). *School mathematics: Options for the 1990s.* (Chairman's report of a conference). Washington, DC: U.S. Government Printing Office.

Romberg, T.A., & Price, G.G. (1983). *Staff development: Eighty-second yearbook of the National Society for Study in Education (Part II).* Chicago: University of Chicago Press.

Russell, J. (1978). *The acquisition of knowledge.* New York: St. Martin's Press.

Skemp, R.R. (1979). *Intelligence, learning, and action: A foundation for theory and practice in education.* Chicester: Wiley.

APPENDIX A

OVERVIEW OF STANDARDS

INTRODUCTION

Background

These standards are one facet of the mathematics education community's response to the call for reform in the teaching and learning of mathematics.[1] They reflect, and are an extension of, the community's responses to those demands for change.[2] Inherent in this document is a consensus that all students need to learn more, and often different, mathematics and that instruction in mathematics must be significantly revised.

As a function of NCTM's leadership in current efforts to reform school mathematics, the Commission on Standards for School Mathematics was established by the Board of Directors and charged with two tasks:

1. Create a coherent vision of what it means to be mathematically literate in a world that relies on calculators and computers to carry out mathematical procedures, and in a world where mathematics is rapidly growing and is extensively being applied in diverse fields.

2. Create a set of standards to guide revision of school mathematics curriculum and associated evaluation toward this vision.

The Working Groups of the Commission prepared the Standards in response to this charge.

Key terms used in the development of this document include:

Curriculum. A curriculum is an operational plan for instruction that details: what mathematics students need to know, how students are to achieve the identified curricular goals, what teachers are to do to help students develop their mathematical knowledge, and the context in which learning and teaching occurs. In this context, the term describes what many would label as the "intended curriculum," or the "plan for a curriculum."
Evaluation. Standards have been articulated for evaluating both student performance and curricular programs, with an emphasis on the role of evaluative measures in gathering information upon which teachers can base subsequent instruction. The standards also acknowledge the value of gathering information about student growth and achievement for research and administrative purposes.

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1 See *A Nation at Risk* (National Commission on Excellence in Education, 1983), or *Educating Americans for the 21st Century* (National Science Board Commission on Precollege Education in Mathematics, Science and Technology, 1983).

2 *What is Fundamental and What is Not* (Conference Board of the Mathematical Sciences, 1983a); *New Goals for Mathematical Sciences Education* (Conference Board of the Mathematical Sciences, 1983b); and *School Mathematics: Options for the 1990's* (Romberg, 1984).

Standard. A standard is a statement that can be used to judge the quality of a mathematics curriculum or methods of evaluation. Thus, standards are statements about what is valued.

The Need for Standards for School Mathematics

For NCTM the development of standards as statements of criteria for excellence in order to produce change was our focus. Schools, and in particular, school mathematics, must reflect the important consequences of the current reform movement if our students are to be adequately prepared to live in the 21st century. The standards should be viewed as facilitators of reform.

The Need For New Goals

Our vision of mathematical literacy is based on a reexamination of educational goals. Historically, societies have established schools to:

-- transmit aspects of the culture to the young, and

-- direct students toward and provide them with an opportunity for self-fulfillment.

Thus, the goals all schools try to achieve are both a reflection of the needs of society and the needs of students.

Calls for reform in school mathematics suggest that new goals are needed. All industrialized countries have experienced a shift from an industrial to an information society, a shift that has transformed both the aspects of mathematics that need to be transmitted to students and the concepts and procedures they must master if they are to be self-fulfilled, productive citizens in the next century.

The Information Society. This social and economic shift can be attributed, at least in part, to the availability of low-cost calculators, computers, and other technology. The use of this technology has dramatically changed the nature of the physical, life, and social sciences; business; industry; and government. Today, the pace of economic change is being accelerated by continued innovation in communications and computer technology.

New Societal Goals. The educational system of the industrial age does not meet the economic needs of today. New social goals for education include: (1) mathematically literate workers, (2) lifelong learning, (3) opportunity for all, and (4) an informed electorate. Implicit in these goals is a school system organized to serve as an important resource for all citizens throughout their lives.

Mathematically literate workers. Businesses no longer seek workers with strong backs, clever hands, and "shopkeeper" arithmetic skills. In fact, it is claimed that the "most significant growth in new jobs between now and the year 2000 will be in fields requiring the most education" (Lewis, 1988, p. 468). Henry Pollak (1987), a noted industrial mathematician, recently summarized the mathematical expectations for new employees in industry:

-- the ability to set up problems with the appropriate operations;

-- knowledge of a variety of techniques to approach and work on problems;
-- understanding of the underlying mathematical features of a problem;
-- the ability to work with others on problems;
-- the ability to see the applicability of mathematical ideas to common and complex problems;
-- preparation for open problem situations, since most real problems are not well formulated; and
-- belief in the utility and value of mathematics.

Notice the difference between the skills and training inherent in these expectations and those acquired by students working independently to solve explicit sets of drill and practice exercises. While mathematics is not taught in schools solely so students can get jobs, we are convinced that in-school experiences reflect to some extent those of today's workplace.

Lifelong learning. Employment counselors, cognizant of the rapid changes in technology and employment patterns, are claiming that, on average, workers will change jobs at least four to five times during the next 25 years, and that each job will require retraining in communication skills. Thus, a flexible workforce capable of lifelong learning is required; this implies that school mathematics must emphasize a dynamic form of literacy. Problem solving--which includes the ways in which problems are represented, the meanings of the language of mathematics, and the ways in which one conjectures and reasons--must be central to schooling so that students can explore, create, accommodate to changed conditions, and actively create new knowledge over the course of their lives.

Opportunity for all. The social injustices of past schooling practices can no longer be tolerated. Current statistics indicate that those who study advanced mathematics are most often white males. Women and most minorities study less mathematics and are seriously underrepresented in careers utilizing science and technology. Creating a just society in which women and various ethnic groups enjoy equal opportunities and equitable treatment is no longer an issue. Mathematics has become a critical filter for employment and full participation in our society. We cannot afford to have the majority of our population mathematically illiterate: Equity has become an economic necessity.

Informed electorate. In a democratic country in which political and social decisions involve increasingly complex technical issues, an educated, informed electorate is critical. Current issues--such as environmental protection, nuclear energy, defense spending, space exploration, and taxation--involve many interrelated questions. Their thoughtful resolution requires technological knowledge and understanding. In particular, citizens must be able to read and interpret complex, and sometimes conflicting, information.

In summary, today's society expects schools to insure that all students have an opportunity to become mathematically literate, are capable of extending their learning, have an equal opportunity to learn, and become informed citizens capable of understanding issues in a technological society. As society changes, so must its schools.

New Goals for Students Educational goals for students must reflect the importance of mathematical literacy. Toward this end, the *Standards*, K-12, articulate five general goals for all students: (1) that they learn to value mathematics, (2) that they become confident in their ability to do mathematics, (3) that they become mathematical problem solvers, (4) that they learn to communicate mathematically, and (5) that they learn to reason mathematically. The curriculum should be permeated with these goals and experiences such that they become commonplace in the lives of students. We are convinced that if students are exposed to the kinds of experiences outlined in the *Standards*, they will gain *mathematical power*. This term denotes an individual's abilities to explore, conjecture, and reason logically, as well as the ability to use a variety of mathematical methods effectively to solve nonroutine problems. This notion is based on recognition of mathematics as more than a collection of concepts and skills to be mastered; it includes methods of investivating and reasoning, means of communication, and notions of context. In addition, for each individual, mathematical power involves the development of personal self-confidence.

Learning to value mathematics. Students should have numerous and varied experiences related to the cultural, historical, and scientific evolution of mathematics so that they can appreciate the role of mathematics in the development of our contemporary society, and explore relationships among mathematics and the disciplines it serves: the physical and life sciences, the social sciences, and the humanities.

Becoming confident in one's own ability. As a result of studying mathematics, students need to view themselves as capable of using their growing mathematical power to make sense of new problem situations in the world around them. To some extent, everybody is a mathematician and does mathematics consciously. To buy at the market, to measure a strip of wallpaper or to decorate a ceramic pot with a regular pattern is doing mathematics. School mathematics must endow all students with a realization that doing mathematics is a common human activity. Having numerous and varied experiences allows students to trust their own mathematical thinking.

Becoming a mathematical problem solver. Development of each student's ability to solve problems is essential if he or she is to be a productive citizen. We strongly endorse the first recommendation of *An Agenda for Action* (National Council of Teachers of Mathematics, 1980): "Problem solving must be the focus of school mathematics" (p. 2). To develop such abilities, students need to work on problems that may take hours, days and even weeks to solve. Although some may be relatively simple exercises to be accomplished independently, others should involve small groups or an entire class working cooperatively. Some problems also should be open-ended with no right answer, or need to be formulated.

Learning to communicate mathematically. Development of a student's power to use mathematics involves learning the signs, symbols, and terms of mathematics. This is best accomplished in problem situations in which students have an opportunity to read, write, and discuss ideas in which the use of the language of mathematics becomes natural. As students communicate their ideas, they learn to clarify, refine, and consolidate their thinking.

Learning to reason mathematically. Making conjectures, gathering evidence, and building an argument to support such notions are fundamental to doing mathematics. In fact, demonstration of good reasoning should be rewarded even more than students' ability to find correct answers.

In summary, the intent of these goals is that students will *become mathematically literate*. This term denotes an individual's ability to explore, to conjecture, and to reason logically, as well as to use a variety of mathematical methods effectively to solve problems. By becoming literate, their mathematical power should develop.

An Overview of the Curriculum and Evaluation Standards

There are 54 standards divided among four categories: grades K-4, 5-8, 9-12, and evaluation. The four categories are arbitrary in that they are not intended to reflect school structure; in fact, we encourage readers to consider these as K-12 standards. In addition, we believe that similar standards need to be developed for both pre-school programs and those beyond high school.

It was our task to prepare the curriculum and evaluation standards that reflect our vision of how the societal and student goals already articulated here could be met. These standards should be seen as an initial step in the lengthy process of bringing about reform in school mathematics.

The Evaluation Standards. The evaluation standards are presented separately not because evaluation should be separated from the curriculum, but because planning for the gathering of evidence about student and program outcomes is different.

Challenge

Such are the background, the general focus, and the intent of our efforts. It is now left to each of you is concerned with the teaching and learning of mathematics to read the *Standards*, to share them with colleagues, and to reflect on their vision. Consider what needs to be done and what you can do, and collaborate with others to plan and implement the *Standards* for the benefit of students, as well as for our social and economic future.

K-4 STANDARDS

STANDARD 1: MATHEMATICS AS PROBLEM SOLVING

In grades K-4, the study of mathematics should emphasize problem solving so that students can:

- use problem-solving approaches to investigate and understand mathematical content;
- formulate problems from everyday and mathematical situations;
- develop and apply strategies to solve a wide variety of problems;
- verify and interpret results with respect to the original problem;
- acquire confidence in using mathematics meaningfully.

STANDARD 2: MATHEMATICS AS COMMUNICATION

In grades K-4, the study of mathematics should include numerous opportunities for communication so that students can:

- relate physical materials, pictures and diagrams to mathematical ideas;
- reflect upon and clarify their thinking about mathematical ideas and situations;
- relate their everyday language to mathematical language and symbols;
- realize that representing, discussing, listening, writing, and reading mathematics are a vital part of learning and using mathematics.

STANDARD 3: MATHEMATICS AS REASONING

In grades K-4, the study of mathematics should emphasize reasoning so that students can:

- draw logical conclusions about mathematics;
- use models, known facts, properties, and relationships to explain their thinking;
- justify their answers and solution processes;
- use patterns and relationships to analyze mathematical situations;
- believe that mathematics makes sense.

STANDARD 4: MATHEMATICAL CONNECTIONS

In grades K-4, the study of mathematics should include opportunities to make connections so that students can:

- link conceptual and procedural knowledge;
- relate various representations of concepts or procedures to one another;
- recognize relationships among different topics in mathematics;
- use mathematics in other curriculum areas;
- use mathematics in their daily lives.

STANDARD 5: ESTIMATION

In grades K-4, the curriculum should include estimation so students can:

- explore estimation strategies;
- recognize when an estimate is appropriate;
- use estimation to determine reasonableness of results;
- apply estimation in working with quantities, measurement, computation, and problem solving.

STANDARD 6: NUMBER SENSE AND NUMERATION

In grades K-4, the mathematics curriculum should include whole number concepts and skills so that students can:

- construct number meanings through real-world experiences and the use of physical materials;

- understand our numeration system by relating counting, grouping, and place-value concepts;
- develop number sense;
- interpret the multiple uses of numbers encountered in the real world.

STANDARD 7: CONCEPTS OF WHOLE NUMBER OPERATIONS
In grades K-4, the mathematics curriculum should include concepts of addition, subtraction, multiplication, and division of whole numbers so that students can:
- develop meaning for the operations by modeling and discussing a rich variety of problem situations;
- relate the mathematical language and symbolism of operations to problem situations and informal language;
- recognize that a wide variety of problem structures can be represented by a single operation;
- develop operation sense.

STANDARD 8: WHOLE NUMBER COMPUTATION
In grades K-4, the mathematics curriculum should develop whole number computation so that students can:
- model, explain, and develop reasonable proficiency with basic facts and algorithms;
- use a variety of mental computation and estimation techniques;
- use calculators in appropriate computational situations;
- select and use computation techniques appropriate to specific problem situations and determine whether the result is reasonable.

STANDARD 9: GEOMETRY AND SPATIAL SENSE
In grades K-4, the mathematics curriculum should include two- and three-dimensional geometry so that students can:
- describe, model, draw, and classify shapes;
- investigate and predict results of combining, subdividing, and changing shapes;
- develop spatial sense;
- relate geometric ideas to number and measurement ideas;
- recognize and appreciate geometry in their world.

STANDARD 10: MEASUREMENT
In grades K-4, the mathematics curriculum should include measurement so that students can:
- understand the attributes of length, capacity, weight, area, volume, time, temperature, and angle;
- develop the process of measuring and concepts related to units of measurement;
- make and use estimates of measurement;
- make and use measurements in problem and everyday situations.

STANDARD 11: STATISTICS AND PROBABILITY
In grades K-4, the mathematics curriculum should include experiences with data analysis and probability so that students can:
- collect, organize, and describe data;
- construct, read, and interpret displays of data;
- formulate and solve problems that involve collecting and analyzing data;
- explore concepts of chance.

STANDARD 12: FRACTIONS AND DECIMALS

In grades K-4, the mathematics curriculum should include fractions and decimals so that students can:

- develop concepts of fractions, mixed numbers and decimals;
- develop number sense for fractions and decimals;
- use models to relate fractions to decimals and to find equivalent fractions;
- use models to explore operations on fractions and decimals;
- apply fractions and decimals in problem situations.

STANDARD 13: PATTERNS AND RELATIONSHIPS

In grades K-4, the mathematics curriculum should include patterns and relationships so that students can:

- recognize, extend, describe, and create a wide variety of patterns;
- represent and describe mathematical relationships;
- explore the use of variables and open sentences to express relationships.

5-8 STANDARDS

STANDARD 1: MATHEMATICS AS PROBLEM SOLVING

In grades 5-8, the mathematics curriculum should include numerous and varied experiences with problem solving as a method of inquiry and application so that students can:

- use problem-solving approaches to investigate and understand mathematical content;
- formulate problems from situations within and outside mathematics;
- develop and apply a variety of strategies to solve problems, with emphasis on multi-step and nonroutine problems;
- verify and interpret results with respect to the original problem situation;
- generalize solutions and strategies to new problem situations;
- acquire confidence in using mathematics meaningfully.

STANDARD 2: MATHEMATICS AS COMMUNICATION

In grades 5-8, the study of mathematics should include opportunities to communicate so that students can:

- model situations using oral, written, concrete, pictorial, graphical, and algebraic methods;
- reflect upon and clarify their own thinking about mathematical ideas and situations;
- develop common understandings of mathematical ideas, including the role of definitions;
- use the skills of reading, listening, and viewing to interpret and evaluate mathematical ideas;
- discuss mathematical ideas and make conjectures and convincing arguments;
- appreciate the value of mathematical notation and its role in the development of mathematical ideas.

STANDARD 3: MATHEMATICS AS REASONING

In grades 5-8, reasoning shall permeate the mathematics curriculum so that students can:

- recognize and apply deductive and inductive reasoning;
- understand and apply reasoning processes, with special attention to spatial reasoning and reasoning with proportions and graphs;
- make and evaluate mathematical conjectures and arguments;
- validate their own thinking;
- appreciate the pervasive use and power of reasoning as a part of mathematics.

STANDARD 4: MATHEMATICAL CONNECTIONS

In grades 5-8, the mathematics curriculum should include investigation of mathematical connections so that students can:

- see mathematics as an integrated whole;
- explore problems and describe results using graphical, numerical, physical, algebraic, and verbal mathematical models or representations;
- use a mathematical idea to further their understanding of other mathematical ideas;
- apply mathematical thinking and modeling to solve problems that arise in other disciplines, such as art, music, psychology, science, and business;
- value the role of mathematics in our culture and society.

STANDARD 5: NUMBER AND NUMBER RELATIONSHIPS

In grades 5-8, the mathematics curriculum should include the continued development of number and number relationships so that students can:

- understand, represent, and use numbers in a variety of equivalent forms (integer, fraction, decimal, percent, exponential, and scientific notation) in real-world and mathematical problem situations;
- develop number sense for whole numbers, fractions, decimals, integers, and rational numbers;
- understand and apply ratios, proportions, and percents in a wide variety of situations;
- investigate relationships among fractions, decimals, and percents;
- represent numerical relationships in one- and two-dimensional graphs.

STANDARD 6: NUMBER SYSTEMS AND NUMBER THEORY

In grades 5-8, the mathematics curriculum should include the study of number systems and number theory so that students can:

- understand and appreciate the need for numbers beyond the whole numbers;
- develop and use order relations for whole numbers, fractions, decimals, integers, and rational numbers;
- extend their understanding of whole number operations to fractions, decimals, integers, and rational numbers;
- understand how the basic arithmetic operations are related to one another;
- develop and apply number theory concepts (such as primes, factors, and multiples) in real-world and mathematical problem situations.

STANDARD 7: COMPUTATION AND ESTIMATION

In grades 5-8, the mathematics curriculum should include development of the concepts underlying computation and estimation in various contexts so that students can:

- compute with whole numbers, fractions, decimals, integers, and rational numbers;
- develop, analyze, and explain procedures for computation and techniques for estimation;
- develop, analyze, and explain methods for solving proportions;
- select and use an appropriate method for computing from among mental arithmetic, paper-and-pencil, calculator, and computer methods;
- use computation, estimation, and proportions to solve problems;
- use estimation to check the reasonableness of results.

STANDARD 8: PATTERNS AND FUNCTIONS

In grades 5-8, the mathematics curriculum should include explorations of patterns and functions so that students can:

- describe, extend, analyze, and create a wide variety of patterns;
- describe and represent relationships using tables, graphs, and rules;
- analyze functional relationships to explain how change in one quantity affects change in another;
- use patterns and functions to represent and solve problems.

STANDARD 9: ALGEBRA

In grades 5-8, the mathematics curriculum should include explorations of algebraic concepts and processes so that students can:

- understand the concepts of variable, expression, and equation;
- represent situations and number patterns with tables, graphs, verbal rules, and equations, and explore the interrelationships of these representations;

- analyze tables and graphs to identify properties and relationships;
- develop confidence in solving linear equations using concrete, informal, and formal methods;
- investigate inequalities and nonlinear equations informally;
- apply algebraic methods to solve a variety of real-world and mathematical problems.

STANDARD 10: STATISTICS
In grades 5-8, the mathematics curriculum should include explorations of statistics in real-world situations so that students can:
- systematically collect, organize, and describe data;
- construct, read, and interpret tables, charts, and graphs;
- make inferences and convincing arguments based on data analysis;
- evaluate arguments based on data analysis;
- develop an appreciation for statistical methods as powerful means for decision making.

STANDARD 11: PROBABILITY
In grades 5-8, the mathematics curriculum should include explorations of probability in real world situations so that students can:
- model situations by devising and carrying out experiments or simulations to determine probabilities;
- model situations by constructing a sample space to determine probabilities;
- appreciate the power of using a probability model through comparison of experimental results with mathematical expectations;
- make predictions based on experimental or mathematical probabilities;
- develop an appreciation for the pervasive use of probability in the real world.

STANDARD 12: GEOMETRY
In grades 5-8, the mathematics curriculum should include the study of the geometry of one, two, and three dimensions in a variety of situations so that students can:
- identify, describe, compare, and classify geometric figures;
- visualize and represent geometric figures with special attention to developing spatial sense;
- explore transformations of geometric figures;
- represent and solve problems using geometric models;
- understand and apply geometric properties and relationships;
- develop an appreciation of geometry as a means of describing the physical world.

STANDARD 13: MEASUREMENT
In grades 5-8, the mathematics curriculum should include extensive concrete experiences using measurement so that students can:
- extend their understanding of the process of measurement;
- estimate, make, and use measurements to describe and compare phenomena;
- select appropriate units and tools to measure to the level of accuracy required in a particular situation;
- understand the structure and use of systems of measurement;
- extend their understanding of the concepts of perimeter, area, volume, angle measure, capacity, and weight/mass;
- develop the concepts of rates and other derived and indirect measurements;
- develop formulas and procedures for determining measures to solve problems.

STANDARD 1: MATHEMATICS AS PROBLEM SOLVING

In grades 9-12, the mathematics curriculum should include the refinement and extension of methods of mathematical problem solving so that all students can:

- use, with increasing confidence, problem-solving approaches to investigate and understand mathematical content;
- apply integrated mathematical problem-solving strategies to solve problems from within and outside of mathematics;
- recognize and formulate problems from situations within and outside of mathematics;
- apply the process of mathematical modeling to real-world problem situations.

STANDARD 2: MATHEMATICS AS COMMUNICATION

In grades 9-12, the mathematics curriculum should include the continued development of language and symbolism to communicate mathematical ideas so that all students can:

- reflect upon and clarify their thinking about mathematical ideas and relationships;
- formulate mathematical definitions and express generalizations (potential theorems) discovered through investigations;
- express mathematical ideas orally and in writing;
- read written presentations of mathematics with understanding;
- ask clarifying and extending questions related to mathematics they have read or heard about;
- appreciate the power, elegance, and economy of mathematical notation and its role in the development of mathematical ideas.

STANDARD 3: MATHEMATICS AS REASONING

In grades 9-12, the mathematics curriculum should include numerous and varied experiences that reinforce and extend logical reasoning skills so that all students can:

- make and test conjectures;
- formulate counterexamples;
- follow logical arguments;
- judge the validity of arguments;
- construct simple valid arguments;

and so that, in addition, college-intending students can:

- construct proofs for mathematical assertions, including indirect proofs and proofs by mathematical induction.

STANDARD 4: MATHEMATICAL CONNECTIONS

In grades 9-12, the mathematics curriculum should include investigation of the connections and interplay among various mathematical topics and their application so that all students can:

- recognize equivalent representations of the same concept;
- relate procedures in one representation to procedures in an equivalent representation;
- utilize and value the connections among mathematical topics;
- utilize and value the connections between mathematics and other disciplines.

STANDARD 5: ALGEBRA

In grades 9-12, the mathematics curriculum should include the continued study of algebraic concepts and methods so that all students can:

- represent situations that involve variable quantities with expressions, equations, inequalities, and matrices;
- use tables and graphs as tools to interpret expressions, equations, and inequalities;
- operate on expressions and matrices, and solve equations and inequalities;
- appreciate the power of mathematical abstraction and symbolism;

and so that, in addition, college-intending students can:
- use matrices to solve linear systems;
- demonstrate technical facility with algebraic transformations, including techniques based on the theory of equations.

STANDARD 6: FUNCTIONS

In grades 9-12, the mathematics curriculum should include the continued study of functions so that all students can:
- model real-world phenomena with a variety of functions;
- represent and analyze relationships using tables, rules, and graphs;
- translate among tabular, symbolic, and graphical representations of functions;
- recognize that a variety of problem situations can be modeled by the same type of function;
- analyze the effects of parameter changes on the graphs of functions;

and so that, in addition, college-intending students can:
- understand operations on, and the general properties and behavior of, classes of functions.

STANDARD 7: GEOMETRY FROM A SYNTHETIC PERSPECTIVE

In grades 9-12, the mathematics curriculum should include the continued study of the geometry of two and three dimensions so that all students can:
- interpret and draw three-dimensional objects;
- represent problem situations with geometric models and apply properties of figures;
- classify figures in terms of congruence and similarity and apply these relationships;
- deduce properties of, and relationships between, figures from given assumptions;

and so that, in addition, college-intending students can:
- develop an understanding of an axiomatic system through investigating and comparing various geometries.

STANDARD 8: GEOMETRY FROM AN ALGEBRAIC PERSPECTIVE

In grades 9-12, the mathematics curriculum should include the study of the geometry of two and three dimensions from an algebraic point of view so that all students can:
- translate between synthetic and coordinate representations;
- deduce properties of figures using transformations and rising coordinates;
- identify congruent and similar figures using transformations;
- analyze properties of Euclidean transformations and relate translations to vectors;

and so that, in addition, college-intending students can:
- deduce properties of figures using vectors;
- apply transformations, coordinates, and vectors in problem solving.

STANDARD 9: TRIGONOMETRY

In grades 9-12, the mathematics curriculum should include the study of trigonometry so that all students can:

- apply trigonometry to problem situations involving triangles;
- explore periodic real-world phenomena using the sine and cosine functions;

and so that, in addition, college-intending students can:

- understand the connection between trigonometric and circular functions;
- use circular functions to model periodic real-world phenomena;
- apply general graphing techniques to trigonometric functions;
- solve trigonometric equations and verify trigonometric identities;
- understand the connections between trigonometric functions and polar coordinates, complex numbers, and series.

STANDARD 10. STATISTICS

In grades 9-12, the mathematics curriculum should include the continued study of data analysis and statistics so that all students can:

- construct and draw inferences from charts, tables, and graphs that summarize data from real-world situations;
- use curve-fitting to predict from data;
- understand and apply measures of central tendency, variability, and correlation;
- understand sampling and recognize its role in statistical claims;
- design a statistical experiment to study a problem, conduct the experiment, and interpret and communicate the outcomes;
- analyze the effects of data transformations on measures of central tendency and variability;

and so that, in addition, college-intending students can:

- transform data to aid in data interpretation and prediction;
- test hypotheses using appropriate statistics.

STANDARD 11: PROBABILITY

In grades 9-12, the mathematics curriculum should include the continued study of probability so that all students can:

- use experimental or theoretical probability, as appropriate, to represent and solve problems involving uncertainty;
- use simulations to estimate probabilities;
- understand the concept of random variable;
- create and interpret discrete probability distributions;
- describe, in general terms, the normal curve and use its properties to answer questions about sets of data that are assumed to be normally distributed;

and so that, in addition, college-intending students can:

- apply the concept of random variable to generate and interpret probability distributions including binomial, uniform, normal, and chi-square.

STANDARD 12: DISCRETE MATHEMATICS

In grades 9-12, the mathematics curriculum should include topics from discrete mathematics so that all students can:

- represent problem situations using discrete structures such as finite graphs, matrices, sequences, and recurrence relations;
- represent and analyze finite graphs using matrices;
- develop and analyze algorithms;
- solve enumeration and finite probability problems;

and so that, in addition, college-intending students can:

- represent and solve problems using linear programming and difference equations;
- investigate problem situations that arise in connection with computer validation and application of algorithms.

STANDARD 13: CONCEPTUAL UNDERPINNINGS OF CALCULUS

In grades 9-12, the mathematics curriculum should include the informal exploration of calculus concepts from both a graphical and numerical perspective so that all students can:

- determine maximum and minimum points of a graph and interpret the results in problem situations;
- investigate limiting processes by examining infinite sequences and series and areas under curves;

and so that, in addition, college-intending students can:

- understand the conceptual foundations of limit, area under a curve, rate of change, and slope of a tangent line, and their applications in other disciplines;
- analyze the graphs of polynomial, rational, radical, and transcendental functions.

STANDARD 14: MATHEMATICAL STRUCTURE

In grades 9-12, the mathematics curriculum should include the study of mathematical structure so that all students can:

- compare and contrast the real number system and its various subsystems in terms of structural characteristics;
- understand the logic of algebraic procedures;
- appreciate that seemingly different mathematical systems may be essentially the same;

and so that, in addition, college-intending students can:

- develop the complex number system and demonstrate facility with its operations;
- prove elementary theorems within various mathematical structures, such as groups and fields;
- develop an understanding of the nature and purpose of axiomatic systems.

EVALUATION STANDARDS

STANDARD 1: ALIGNMENT
In assessing students' learning, assessment methods and tasks should be aligned with the curriculum in terms of:
- its goals, objectives, and mathematical content;
- the relative emphases it gives to various topics and processes and their relationships;
- its instructional approaches and activities, including the use of calculators, computers, and manipulatives.

STANDARD 2: MULTIPLE SOURCES OF INFORMATION
Decisions concerning students' learning should be based on the convergence of information obtained from a variety of sources. These sources should embody tasks that:
- demand different kinds of mathematical thinking;
- present the same mathematical concept or procedure in different contexts, formats, and problem situations.

STANDARD 3: APPROPRIATE ASSESSMENT METHODS AND USES
Assessment methods and instruments should be selected on the basis of:
- the type of information sought;
- the use to which the information will be put;
- the developmental level and maturity of the student.

Use of assessment data for purposes other than those intended is inappropriate.

STANDARD 4: MATHEMATICAL POWER
The assessment of students' mathematical knowledge should seek information about their:
- ability to apply their knowledge to solve problems within mathematics and in other disciplines;
- ability to use mathematical language to communicate ideas;
- ability to reason and analyze;
- knowledge and understanding of concepts and procedures;
- disposition towards mathematics;
- understanding of the nature of mathematics;

and the extent to which these aspects of students' mathematical knowledge are integrated.

STANDARD 5: PROBLEM SOLVING
The assessment of students' ability to solve problems should provide evidence that they can:
- formulate problems;
- apply a variety of strategies to solve problems;
- solve problems;
- verify and interpret results;
- generalize solutions.

STANDARD 6: COMMUNICATION
Assessment of students' ability to communicate mathematics should provide evidence that they can:
- express mathematical ideas by speaking, writing, demonstrating, and depicting them visually;

- understand, interpret, and evaluate mathematical ideas that are presented in written, oral or visual form;
- use mathematical vocabulary, notation, and structure to represent ideas, describe relationships, and model situations.

STANDARD 7: REASONING

The assessment of students' ability to reason mathematically should provide evidence that they can:

- use inductive reasoning to recognize patterns and form conjectures;
- use to develop plausible arguments for mathematical statements;
- use proportional and spatial reasoning to solve problems;
- use deductive reasoning to verify conclusions, judge the validity of arguments, and construct valid arguments;
- analyze situations to determine common properties and structures;
- appreciate the axiomatic nature of mathematics.

STANDARD 8: MATHEMATICAL CONCEPTS

Assessment of students' knowledge and understanding of mathematical concepts should provide evidence that they can:

- label, verbalize, and define concepts;
- identify and generate examples and nonexamples;
- use models, diagrams, and symbols to represent concepts;
- translate from one mode of representation to another;
- recognize the various meanings and interpretations of concepts;
- identify properties of a given concept and recognize conditions that determine a particular concept;
- compare and contrast concepts with other related concepts.

In addition, assessment should provide evidence of the extent to which students have integrated their knowledge of various concepts.

STANDARD 9: MATHEMATICAL PROCEDURES

The assessment of students' knowledge of procedures should provide evidence that they can:

- recognize when it is appropriate to use a procedure;
- give reasons for the steps in a procedure;
- reliably and efficiently execute procedures;
- verify results of procedures empirically (e.g., using models) or analytically;
- recognize correct and incorrect procedures;
- generate new procedures and extend or modify familiar ones;
- appreciate the nature and role of procedures in mathematics.

STANDARD 10: MATHEMATICAL DISPOSITION

The assessment of students' mathematical disposition should seek information about their:

- confidence in using mathematics to solve problems, to communicate ideas, and to reason;
- flexibility in exploring mathematical ideas and trying alternative methods in solving problems;
- willingness to persevere at mathematical tasks;
- interest, curiosity and inventiveness in doing mathematics;
- inclination to monitor and reflect upon their own thinking and performance;
- appreciation of the role of mathematics in our culture and its value as a tool and as a language.

STANDARD 11: INDICATORS FOR PROGRAM EVALUATION
When evaluating a mathematics program is consistency with the NCTM Standards, indicators of the program's match to the Standards should be collected on:
- student outcomes;
- program expectations and support;
- equity for all students;
- curriculum review and change.

In addition, indicators of the program's match to the *Standards* should be collected on curriculum and instructional resources and instruction. These are discussed explicitly in Evaluation Standards 12 and 13.

STANDARD 12: CURRICULAR AND INSTRUCTIONAL RESOURCES
When evaluating a mathematics program's consistency with the NCTM Curriculum Standards, examination of curricular and instructional resources should focus on:
- goals, objectives, and mathematical content;
- relative emphases of various topics and processes and their relationships;
- instructional approaches and activities;
- articulation across grades;
- assessment methods and instruments;
- availability of technological tools and support materials.

STANDARD 13: INSTRUCTION
When evaluating a mathematics program's consistency with the NCTM Curriculum Standards, instruction and the environment in which it takes place should be examined, with special attention to:
- mathematical content and its treatment;
- relative emphases assigned to various topics and processes and the relationships among them;
- opportunity to learn;
- instructional resources and classroom climate;
- assessment methods and instruments used;
- articulation of instruction across grades.

STANDARD 14: EVALUATION TEAM
Program evaluation should be planned and conducted with the involvement of:
- individuals with expertise and training in mathematics education;
- individuals with expertise and training in program evaluation;
- decision makers for the mathematics program;
- users of the information from the evaluation.

AN EXAMPLE OF A CURRICULUM STANDARD

STANDARD 10: STATISTICS

In grades 5-8, the mathematics curriculum should include the exploration of statistics in real-world situations so that students can:

- systematically collect, organize, and describe data;
- construct, read, and interpret tables, charts, and graphs;
- make inferences and convincing arguments based on data analysis;
- evaluate arguments based on data analysis;
- develop an appreciation for statistical methods as powerful means for decision making.

Focus

In this age of information and technology, there is an ever-increasing need to understand how information is processed and translated into usable knowledge. Because of society's expanding use of data in prediction and decision making, it is important that students develop an understanding of the concepts and processes used in analyzing data. Knowledge of statistics is necessary for students to become intelligent consumers who can make informed and critical decisions.

In grades K-4, students begin to explore elementary ideas of statistics by gathering data appropriate to their grade level, organizing it in charts or graphs, and reading information from their displays. These concepts should be continued and expanded in the middle grades. Students in grades 5-8 have a keen interest in trends in music, movies, fashion, and sports. Investigation of how such trends are developed and communicated is an excellent motivator for the study of statistics. Students need to be actively involved in each of the steps that comprise statistics, from the process of gathering information to the communication of findings and statistical results.

Identifying the range or average of a data set, constructing simple graphs, and reading data points as answers to specific questions are important activities, but they reflect only a very narrow aspect of statistics. Instead, instruction in statistics should focus on the active involvement of students in the entire process: formulating key questions; collecting and organizing data; representing the data using graphs, tables, frequency distributions, and summary statistics; analyzing the data; making conjectures; and communicating information in a convincing way. Students' understanding of statistics also is enhanced by opportunities to evaluate others' arguments. This exercise is of particular importance to all students, as so much advertising, forecasting, and public policy development is based on data analysis.

Middle-school students' curiosity about themselves, their peers, and their surroundings can motivate the study of statistics. The data to be gathered, organized, and studied should be interesting and relevant; their interest in self and peers, for example, can motivate students to investigate the "average student" in the class or school. First, students must formulate questions as to what determines their concept of an "average student"--age, height, eye color, favorite music or TV show, number of people in family, pets at home, etc. While numerous categories are possible, some discussion will help students to develop a survey instrument that will provide appropriate data. Sampling procedures are a critical issue in data collection. Which students should be surveyed to determine Mr. or Ms. Average? Must every student be questioned? If not, how can randomness in the sampling be assured and how many samples are needed to provide enough data to describe the average student?

Random samples, bias in sampling procedures, and limited samples all are important considerations. For instance, would collecting data from the men's and women's basketball teams provide good information to determine the average height of a college student? Will a larger sample reveal a more accurate picture of the percentage of students with brown hair? The following graph illustrates the results of increasing the sample size.

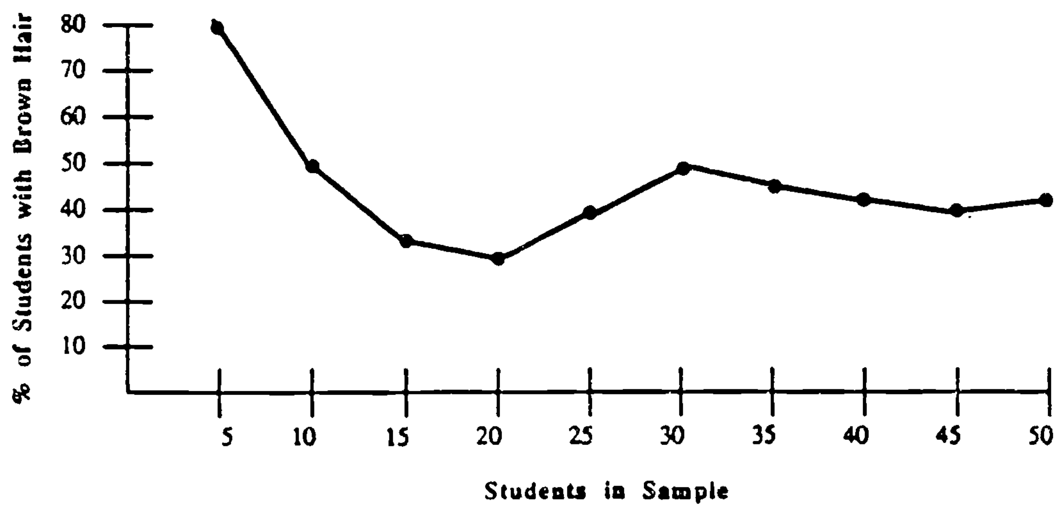

Figure 10.1: Graph of brown-haired students

number with brown hair	4	5	5	6	10	15	16	17	18	21
students sampled	5	10	15	20	25	30	35	40	45	50

Figure 10.2: Data table

Data presentation can take various forms: charts, tables, plots (including stem and leaf, box and whiskers, and scatter), and graphs (such as bar, circle, or line). Each offers its own unique visual presentation of the data. Each form wields a different impact on the picture of the information being presented, and each conveys a different perspective. The choice of form depends on the questions that are to be answered. Using the same data, graphs can be developed using several different scales to show how the change of scale can dramatically alter the visual message that is communicated.

Computer software can greatly enhance the organization and representation of data. Data-base programs can provide information for students' investigation and can record data, sort it quickly by various categories, and organize it in a variety of ways. Other programs can be used to construct plots and graphs for data display. Scale changes can be made to compare different pictures of the same information. This technological tool frees students to spend more time exploring the essence of statistics: analyzing data from many viewpoints, drawing inferences, and constructing and evaluating arguments.

A particular point to be raised with students concerns "average" as it relates to numerical and nonnumerical data. While there are several measures of central tendency, students are generally exposed only to the mean or median, yet the mode may be the best "average" for a set of non-numerical data.

Students also should explore the concepts of *center* and *dispersion of data*. The following activity includes all of the important elements presented in this standard and illustrates the use of box-and-whisker plots as an effective means of describing data and showing variation.

> **A class is divided into two large groups, and then subdivided into pairs. One student in each pair estimates when one minute has passed while the other watches the clock and records the actual time. All of the students in one group concentrate on the timing task, while half of the students in the second exert constant efforts to distract their partners. The box plots show that the median times for the two groups were about the same, but the times for the distracted group have greater variation. Note that in the distracted group, one data point is far enough removed from the others to be an outlier.**

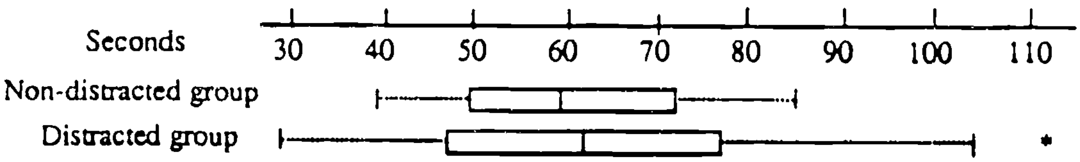

Figure 10.3: Time estimates

Sports statistics and other real data provide students with settings in which they can generate new data and investigate a variety of conjectures. The table below contains information from a NBA championship series game between Los Angeles and Boston.

Player	Min	FG-A	Reb	Asst.	Pts.
Worthy	37	8-19	8	5	20
Johnson	34	8-14	1	12	19
Bird	31	8-14	6	9	19
McHale	32	10-16	9	0	26

Figure 10.4: NBA championship series

From this table, students can be asked to generate such new information as: points/minute, rebounds/minute, points/field goals attempted. Who is the best percentage shooter? What is the height of each player? Determine rebounds/inch of height; points/inch of height.

A problem such as this is ideally suited to the curious nature of middle-school students and opens up a world of questions and investigations to them.

Formulating key questions, interpreting graphs and charts, and solving problems are important goals in the study of statistics. Statistics can help answer questions that do not lend themselves to direct measurement. Once data is collected and organized, questions such as the following can guide students in interpreting the data:

What appears most often?
What trends appear in the data?
What is the significance of outliers?
What interpretations can we draw from these data, and can we use the interpretations to make predictions?
What difficulties might be encountered when extending the interpretations or predictions to other, related problems?
What additional data could we collect in order to verify or disprove the ideas developed from these data?

All forms of media are full of graphical representations of data and different kinds of statistical claims, all of which can be used to motivate discussion of the message being conveyed and the arguments being presented in the data.

NEXT STEPS

Changing School Mathematics

Deciding on the content for school mathematics is an initial step in the needed change process. So that the next steps proceed in harmony with the Standards, both the nature of the needed changes and the implied strategy for change should be understood. We are convinced, given the overwhelmingly positive response to the *Working Draft* of the *Standards*, that there are hundreds of teachers and other mathematics educators eager to bring about changes in school mathematics. In fact, we are optimistic that such changes can and will be accomplished.

Needed Next Steps

Curriculum Development. The Standards are a framework for curriculum development. However, there is no scope and sequence chart, nor is there a listing of topics by specific grade level. Although a coherent network of relationships exists among the identified content topics, multiple paths are available throughout this network. What we have done is to identify the key elements, or nodes, of the network to be included in a quality mathematics curriculum.

Textbooks and Other Materials. While we are aware that the curriculum program in many schools is geared to their textbooks, we expect the *Standards* to be used as criteria for measuring text content.

Tests. Tests have an influence on what actually gets taught in a classroom, especially in urban areas where teachers know that the test results will be used, rightly or wrongly, as an evaluation of *them*. New tests must be developed to assess problem solving, reasoning, etc., in a valid way to ensure that these topics are taught in *all* classrooms.

Instruction. The spirit and vision of the *Standards* cannot be achieved if instruction is inconsistent with the underlying philosophy they encompass. When specifying the content for a quality mathematics program, it is impossible not to address the accompanying instructional conditions. Thus, the elaboration of each standard deliberately contains implications for instruction and includes expectations about teacher actions such as the use of a variety of sequences, grouping procedures, instructional strategies, and techniques for evaluation.

Teacher Inservice. While we are confident that many teachers are now prepared and ready to teach the kind of mathematics program outlined in the *Standards*, many other teachers will need and demand additional training or refresher courses. These programs need to be developed in collaboration with the teachers.

Teacher Education. Prospective teachers must be taught in a manner similar to how they are to teach--explore, conjecture, communicate, reason, and so forth. Colleges of education and mathematical sciences departments should reconsider their teacher preparation programs in light of these curriculum and evaluation criteria.

Technology. Throughout each standard, we have assumed that appropriate technology would be available for use in classroom instruction. Calculators, computers, courseware, and manipulative materials are necessary for good mathematics instruction; the teacher can no longer rely solely on a blackboard, chalk, paper, pencils, and a text.

Differential Student Ability. The consequences of dealing with students with different talents, achievements, and interests has led to such practices as grouping, tracking, and special programs for gifted or handicapped students who need and deserve special attention. However, we believe that *all* students can benefit from an opportunity to study the core curriculum specified in the *Standards.*

Equity. As a pluralistic, democratic society, we cannot continue to discourage women and minority students from the study of mathematics. We believe that current tracking procedures often are inequitable and we challenge all to change current practice by developing instructional activities and programs to directly address this issue.

Working Conditions. In too many schools, teachers will find it difficult to teach the mathematical topics or create the instructional environments envisioned in these *Standards* because of local constraints such as directives about chapters or pages to cover, time for instruction, and tests. In particular, in many grades too little time is spent on mathematics instruction. Teachers and students should spend an hour a day on mathematics at all grades, as well as take advantage of the many opportunities to connect mathematics with other school subjects.

Research. The *Standards* are based on a set of values (philosophical positions) about mathematics for students, and the way instruction should proceed. These values not only are consistent with current research findings but also establish a new research agenda. In the redesign of school mathematics, much careful research is needed.

Summary

The National Council of Teachers of Mathematics has created a vision about:

-- mathematical power for all in a technological society;
-- mathematics as something one does--solve problems, communicate, reason;
-- a curriculum for all which includes a broad range of content, a variety of contexts, and deliberate connections;
-- the learning of mathematics as an active, constructive process;
-- instruction based on problem situations;
-- evaluation as a means of improving instruction, learning, and programs.

Keeping these points in mind, collectively we have a rare opportunity to provide the kind of leadership that will make real, substantive changes in school mathematics. These changes will ensure that all students possess both a suitable and a sufficient mathematical background to be productive citizens in the next century.

THE URBAN MATHEMATICS COLLABORATIVE PROJECT: C^2ME AS A CASE STUDY ON TEACHER PROFESSIONALISM

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Wisconsin Center for Education Research

INTRODUCTION

> *Five years ago you couldn't get permission for a professional leave. You had to take a sick day. You had to lie. The professional days was supposed to be used only for something in your area and was approved of only by the administration. The administration might decide that professional development consists of sitting around and reading the desegregation order. That's demeaning. The in-service sessions were made up of garbage. You had no hand in helping to decide what is going to be of value to you as a professional.*
>
> *Now, a major point for all of us is the chance to work on our professional development ourselves. We are able to expose ourselves to situations that we haven't had in the past. For instance, conferences where we meet with people who run businesses, workshops on the use of calculators and computers, setting aside time at the meetings to talk with teachers in our system, talking about common goals and problems with people in the university and in business and industry.*
> [A quote from a Cleveland, Ohio, high school mathematics teacher in 1988 (Bruckerhoff, 1991, p. B-25).]

High school and middle school mathematics teachers employed by the Cleveland Public Schools (CPS) work in aging schools with corridors patrolled by uniformed guards. In 1989, the 12 comprehensive high schools (Grades 9-12) enrolled nearly 14 000 students and the 20 intermediate schools (Grades 7-8) enrolled nearly 10 000 from Cleveland's population of over 500 000 people. Serving a city situated in the "rust belt" and hard hit by a decline in industrial manufacturing of steel-made products, the schools face an ever-increasing student population living in poverty. More than 60 per cent of all students in the district in 1989 were from families living at or below the poverty level. Approximately 70 per cent of the families served by the CPS qualified for low-cost or federally funded school lunches. Nearly half of the students enrolled in seventh-grade were projected by the district to drop out of school without a diploma; 17 per cent of students in high school drop out each year. Students come to school with problems of teenage pregnancy, drugs, and abusive home situations. Teachers' records indicate that between one-third and two-thirds of their students are absent from class on a regular basis.

Cleveland mathematics teachers, with the support and leadership of the district mathematics supervisor, strive to teach mathematics under less than desirable conditions. The frequent changes in district superintendents (four in a period of five years); the magnitude of the economic and social problems of their students; and imposed extra duties of policing the corridors between class periods and supervising the lunch room all serve to isolate teachers. Teachers are isolated from each other. Teachers are isolated from changes occurring in the field of mathematics. Teachers are isolated from those who are using mathematics. The Cleveland Collaborative for Mathematics Education (C^2ME) was established in 1985 to address, among other issues, this isolation of mathematics teachers. Five years later, mathematics teachers were meeting regularly with members of the corporate world and higher education. One grant and grant extension had been received from the National Science Foundation to operate a problem-solving infusion project. Annual mathematics contests for students were being held at John Carroll University. A Teacher Resource Center was in operation providing support to mathematics teachers and servicing an electronic problem-solving bulletin board for elementary and middle school students. Mathematics teachers were attending summer institutes, site-visits at local industrial sites, workshops, and professional meetings. Teachers had become more knowledgeable about applications of mathematics and had incorporated them into their teaching along with a greater number of problem-solving and calculator activities. Nearly all of the 200 mathematics teachers in the secondary and intermediate schools had participated in some way in collaborative activities; and a third of the teachers were very active in the collaborative.

Mathematics teachers in the CPS gained a new sense of support. "Because of the collaborative we have found new ways to approach the teaching of mathematics," reported one high school teacher. "We have more available to us as teachers that we can share with the students. We are accumulating great amounts of practical experience, problem-solving strategies, and teaching techniques. We are now able to try these things because we have support. In the past there was no support here" (Bruckerhoff, 1991, p. B-21). Teachers began working with each other. One teacher who had only occasionally attended collaborative programs noticed that the teachers who were active in the collaborative were taking advantage of the collaborative's resources, bringing materials back from events, and using these materials in their classes. He overheard talk in the teachers' lounge regarding the new ideas circulating added additional pressure. The collaborative teachers began showing him some of the latest ideas in mathematics education and demonstrating the use of computers. He contrasted this with what it was like before the collaborative, "...we were free to try things but we didn't know the possibilities...[now] we are encouraged to try things and we feel comfortable doing them." One of the outcomes of the collaborative for this teacher was that for the first time in 21 years of teaching, he went to the Ohio Council of Teachers of Mathematics meeting. For this teacher, the collaborative greatly reduced his isolation. "I enjoy coming into work after 21 years because of the change of the collaborative. You can feel alone in that classroom [but] you are not alone. You have backup all over the place. . . . Help is always there. Nothing that you used to dread can go wrong now."

The collaborative helped to influence the image of teaching in inner-city schools. A 22-year-old was in his first semester of teaching at a CPS high school where many of the teachers in the mathematics department had become active in C^2ME. He was fearful of teaching in an inner-city school, but was pleasantly surprised that a city school could be run in an orderly fashion and that the mathematics department could be so supportive. He received help from so many of the teachers that he could not imagine wanting to teach any other place. Another teacher attributes her decision to remain in teaching to the collaborative. "Because of the collaborative my whole attitude toward teaching math has changed. Through things like the problem-solving workshop, calculator workshop, dinner meetings, math clubs, math resource center, etc., I have become rejuvenated and motivated in a whole new light. This has taken place at a time when I was seriously considering getting out of teaching after 18 years. I can honestly say the collaborative has changed my mind" (Webb *et al.*, 1990, p. A-31). The urban mathematics collaborative in Cleveland has increased the self-esteem of mathematics teachers, and broadened their knowledge of mathematics. It has made a salutary difference in the lives of mathematics teachers in Cleveland Public Schools.

THE FORD FOUNDATION'S URBAN MATHEMATICS COLLABORATIVE PROJECT

To better understand the changes in Cleveland, some knowledge of the National Urban Mathematics Collaborative Project will be helpful. In 1984, the Ford Foundation initiated the Urban Mathematics Collaborative (UMC) project to improve mathematics education in inner-city schools in the United States and to identify new models for meeting the on-going professional needs of teachers. In February, 1985, the Foundation awarded five grants to establish urban mathematics collaboratives in Cleveland, Minneapolis-St. Paul, Los Angeles, Philadelphia, and San Francisco. In addition, the Foundation established a Documentation Project to monitor the activities of the new collaboratives and a Technical Assistance Project (TAP) to serve as a source of information for the collaboratives. During the next 18 months, UMC projects were funded in Durham, Pittsburgh, San Diego, St. Louis, Memphis, and New Orleans, bringing to 11 the total number of urban mathematics collaboratives.

In each of the 11 sites, the UMC project (1) supports collaboration among mathematics teachers and between teachers and other mathematicians from institutions of higher education and industry, and (2) encourages teacher membership and participation in a broad-based local mathematics community. As the collaboratives became established, it was evident that a focus on the realities of teaching was timely. Many teachers -- and especially those in inner-city schools -- are overworked, lacking in support and material resources, and isolated from their colleagues, from other professionals, and from the rapidly changing field of mathematics.

Each project began with the premise that developing collegiality among professional mathematicians and teachers can reduce teachers' sense of isolation, foster their professional enthusiasm, expose them to a vast array of new developments and trends in mathematics, and encourage innovation in classroom teaching.

Since 1985, the urban mathematics collaboratives have cultivated local resources -- both financial and human -- and have configured them in a variety of ways to explore new modes of professionalism for teachers and new kinds of relationships between mathematics teachers and those who use mathematics professionally in higher education and in business. Considered individually, each collaborative is a unique, locally-controlled project. But viewed as units of a wide-reaching national network, each comprises an efficient, cost-effective, and comprehensive field experiment that enhances the knowledge and professionalism of participating teachers while serving as a testing ground for new modes of thought and fresh approaches to larger issues of professional enrichment and subject-area expertise. To illustrate the efficacy of the UMC project, a summary of the impact in one collaborative, that of Cleveland, is presented. (Additional information is available in Webb, Pittelman, Romberg, Pitman, Reilly, and Middleton (1991*b*).

THE CLEVELAND COLLABORATIVE FOR MATHEMATICS EDUCATION (C^2ME)

The Cleveland Collaborative for Mathematics Education (C^2ME) was one of the five collaboratives originally established in 1985. The collaborative, which serves the approximately 20 secondary and intermediate school mathematics teachers in the Cleveland Public Schools, is administered through the Cleveland Education Fund.

C^2ME's purpose is to enhance the quality of mathematics education in the Cleveland Public Schools by finding new ways to integrate community resources into the teaching process and by defining new models for meeting the continuing professional needs of teachers. The collaborative has defined its mission as enhancing the professionalism and effectiveness of intermediate and secondary school mathematics teachers in the Cleveland Public Schools by providing opportunities for collegiality, training/professional growth, and curriculum development.

The collaborative's Advisory Board and the Teacher Advisory Board provide input to the collaborative's director and project coordinator. The Advisory Board, which oversees the operation of C²ME, is comprised of representatives of science, education, and business, as well as nine mathematics teachers from the Cleveland Public Schools. The Teacher Advisory Board, which provides an explicit teacher perspective, was established in early 1986 to assist the collaborative in developing its long-range plans and future activities. Teachers were selected to serve on the Teacher Advisory Board on the basis of their participation in C²ME's programs and their dedication to excellence in mathematics education in the Cleveland Public Schools.

During each school year, C²ME has offered a wide variety of activities designed to provide teachers with opportunities for training, information, and collegiality, and to enable them to network with their colleagues, as well as with mathematicians from business, industry, and higher education. The collaborative has sponsored workshops, a dinner symposium, and an end-of-year dinner to honor retiring teachers; initiated the Problem-Solving Infusion Project to develop ways to incorporate problem solving into the seventh- and eighth-grade mathematics curriculum; served as a conduit for the funding of Aetna Math Clubs; initiated and supported mathematics contests; and provided funding to enable teachers to attend regional and national workshops and conferences. In addition, the collaborative has published its own quarterly newsletter; encouraged participation in Cleveland's Teacher Internship Program; helped to facilitate the John Carroll University scholarship program, through which teachers receive awards to cover the cost of college coursework; and encouraged teachers to apply for small grants provided by the Cleveland Education Fund. Finally, the collaborative's multi-purpose Resource Center offers a variety of individual services and support to Cleveland mathematics teachers. The activities held by the Cleveland collaborative over a five year period, from 1985 through July, 1990, are described in detail to provide a better understanding of what a collaborative offers. Follow-up information is provided when available.

C²ME's ACTIVITIES

In keeping with the collaborative's mission to enhance the professionalism and effectiveness of teachers by providing opportunities for collegiality, inservice training, enhancement of classroom instruction, curriculum development, and professional growth, C²ME sponsored a variety of programs for secondary and intermediate school mathematics teachers over the five-year period. In addition to these activities, the collaborative encouraged teachers to participate in the numerous professional development opportunities offered by other area organizations.

Socialization and Networking

One of Cleveland collaborative's original goals was to facilitate sharing, communication, networking, and collegiality among teachers and mathematicians from businesses, industry, and higher education. The collaborative sponsored several programs, including dinner symposia, the Cleveland Mathematics Teachers' Resource Center, and a collaborative newsletter to provide opportunities for teachers to communicate with their peers in the schools, as well as their colleagues in other mathematics-related occupations. The collaborative also played a key role in fostering communication between higher education and the mathematics departments of the school district. This resulted in increased opportunities for CPS mathematics students and teachers, including mathematics contests and competitions, a technology grant awarded to CPS from the Ohio State University, and the Mathematics and Technology Human Resources

Enrichment (MATHREP) Project and MATHCAMP. In addition, the collaborative's Public Relations Committee worked to promote mathematics education within the larger community.

Dinner Symposia

Over the five-year period, the collaborative sponsored nine dinner symposia. The symposia were designed to provide teachers with an opportunity to share ideas with other teachers and business people, as well as to update their knowledge of current topics in mathematics education. The symposia, which were hosted by area corporations and centers of higher education, were well attended by teachers as well as by Advisory Board members, with attendance at individual events reaching as high as 125 participants.

Cleveland Mathematics Teachers' Resource Center

The Cleveland Mathematics Teachers' Resource Center (MTRC) of C^2ME was established at the Metro Campus of Cuyahoga Community College in October, 1985, as a clearinghouse for information and a meeting place for Cleveland public school teachers. The MTRC, which is staffed by teachers and open from 3:00 to 6:00 p.m. Monday through Thursday, provides a centrally located meeting place for teachers, as well as a monthly calendar of events, a data base on teachers, computer access, an electronic bulletin board system which is used by over 100 schools/individuals, and desktop publishing facilities. The MTRC, which serves as the hub of the district's curriculum development and inservice training, was the site of several collaborative events, including meetings of the Teacher Advisory Board. The MTRC is also a center for the collection, review, and distribution of materials. It provides consultation services and distributes a list of recommended materials to each department chair in order to encourage mathematics departments to obtain supplemental textbooks, supplies, and materials, including calculators, to help teachers implement an activities-based approach to mathematics instruction. On Monday of each week during the school year, 20 problems are posted on the electronic bulletin board--one problem for each day of the week for each of four levels: primary, intermediate, junior high, and senior high. Students enter their responses on the bulletin board, and staff of the Center provided feedback to those responses. By the 1991-1992 school year, the number of schools accessing the electronic network was over 100. Four telephone lines were devoted to the network. Schools are encouraged to submit one answer for each problem to encourage cooperative learning. The problem-solving activities are also designed to encourage writing in mathematics.

The level of teacher participation in the Center increased dramatically over the first two years and then diminished slightly. Between the Center's opening on October 1, 1985, and December, 1985, 85 teachers availed themselves of its resources. During the same period in 1986, teachers visited the Center 243 times. By the end of June, 1987, the number of visits had increased to 473. During the 1987-88 school year, however, teachers made only 300 visits to the Center. After this time the regular use of the Center by teachers continued to decline. In 1991-1992, the Center was still in operation, but used as a meeting place by teachers rather than as a resource of information and materials.

Collaborative Newsletter

The collaborative's quarterly newsletter was first published in October, 1985, and distributed to teachers and to Advisory Board members. In the spring of 1987, distribution was expanded so that 300 copies were sent to area businesses. The newsletter announces events, programs, and contests; recognizes teachers for personal accomplishments and C^2ME participation; and prints articles written by teachers who have attended professional meetings and conferences as well as reprints of articles of interest to mathematics teachers. The newsletter was edited by mathematics teachers and the collaborative coordinator. In April, 1989, the collaborative's Program Committee decided that a Newsletter Committee of four volunteer teachers should review and edit the articles. The Newsletter Committee distributed two issues of the newsletter during the 1989-90 school year -- one in the fall and one in the winter. In addition to the newsletter, in March, 1990, the Cleveland Education Fund initiated publication of the *Collaborative Update*. This monthly bulletin lists opportunities for professional development that are available in the Cleveland area, primarily for teachers of mathematics, and secondarily for teachers of English and science.

Mathematics Clubs and Competitions

In 1986, the Aetna Foundation awarded a grant to C²ME to fund mathematics clubs in Cleveland intermediate schools and high schools. Between 1986 and 1990, Aetna contributed over $68,000 to C²ME, including $18 000 in the 1989-90 school year. The effectiveness of the program is indicated by the fact that prior to the award, there were only 10 mathematics clubs in the schools; during 1988-89, 31 of the district's 42 secondary schools operated clubs. By the 1989-90 school year, 26 mathematics clubs in 25 intermediate and high schools participated in the mathematics clubs program. Funds of up to $400 were granted to each of the collaborative's mathematics departments to finance the clubs each year. The money was used for mathematics manipulatives, field trips to area businesses, software, and mathematics competitions.

Grants to schools were contingent upon a commitment to participate in at least three mathematics competitions during the school year. In 1985, the Cleveland Public Schools had only two teams participating in the MATHCOUNTS competition; in 1986, with collaborative support, the number of participating teams increased to 24. In 1986, the Greater Cleveland Council of Teachers of Mathematics (GCCTM) mathematics contest was held in a Cleveland Public School building, the first time that the district opened a school building for the contest. Twenty-nine teams entered from the CPS, representing the largest number of teams ever entered by the Cleveland Schools.

Other contests in which Cleveland students participated included those sponsored by the Ohio Mathematics League; the Mathematics Triathalon, sponsored by C²ME in conjunction with Cleveland State University; and the C²ME/John Carroll University Mathematics Competition. The latter provided an opportunity for collaborative teachers to work with representatives from higher education in a university setting. The competition, which is underwritten by Aetna Life and Casualty, has grown since it was first held in 1987-88. It began as an algebra competition, but geometry was added in 1988, and advanced mathematics in 1989. Approximately 500 students, forming 102 teams representing 20 CPS intermediate and high schools, participated in the 1990 competition -- more than three times the number who participated in the 1987-88 contest. In 1990, for the first time, the contest was held during school hours to demonstrate that participation in a mathematics competition was recognized by the district as a viable reason for students to miss scheduled classes.

MATHREP and *MATHCAMP*

In April, 1987, the Ohio Board of Regents granted $41,000 jointly to the Cleveland collaborative, Baldwin-Wallace College, and the Cleveland Public Schools to fund the Mathematics and Technology Human Resources Enrichment Project (MATHREP), which addressed the under-preparedness of mathematics teachers in the intermediate schools. The funds were for stipends, manipulatives, and books. In Phase I of the project, a three-week MATHREP workshop was held in the summer of 1987 which was attended by 23 participants, including 15 Cleveland Public School teachers. In Phase II, between September, 1987, and January, 1988, nine Saturday meetings were held. Each participating teacher created a project to be used as one week's lesson plans in his/her class. Phase III was a one-week Summer MATHCAMP for the 60 middle school students who scored the highest on a competitive examination and were nominated by Phase II teachers. The camp was held in August, 1988, on the campus of Baldwin-Wallace College.

Community Outreach/Public Relations

To promote networking and collegiality and to strengthen the link that existed between C^{2}ME and the Greater Cleveland Council of Teachers of Mathematics (GCCTM), the collaborative sponsored a display area at the 1986 fall meeting of GCCTM. The exhibit, which was staffed by secondary school mathematics teachers from the Cleveland Public Schools, disseminated information and materials about the collaborative. Although no formal link existed between C^{2}ME and the GCCTM, members of the collaborative were active in the GCCTM and encouraged other teachers to participate. In 1989-90, a collaborative teacher served as the vice-president of the organization. The collaborative and Oberlin College also jointly sponsored special activities for Cleveland Public School teachers as part of Oberlin College's Mayfair Festival in May, 1987.

The collaborative's Public Relations Committee, one of five standing subcommittees that operates under the jurisdiction of its Advisory Board, worked to promote the activities of the collaborative as well as to improve the image of mathematics education within the community. During 1989-90, the committee orchestrated a television public service program and the publication of a story about a middle school mathematics teacher in a local magazine. During Mathematics Awareness Week in 1990, C^{2}ME and the Department of Mathematics and Computer Science at John Carroll University co-sponsored a guest lecture by Dr. Uri Treisman that was attended by 60 people, including 20 C^{2}ME participants. Dr. Treisman, the 1987 recipient of the Charles A. Dana Award for Pioneering Achievement in Higher Education, is currently working with the Dana Foundation to establish the Dana Center for Innovation in Mathematics Education. In his presentation, "Teaching A Changing Population in Turbulent Times," Dr. Treisman discussed his findings regarding fundamental differences in the study methods of several minority groups and their bearing on success in mathematics.

Increased Knowledge of Mathematics Content

The collaborative directed much of its programming toward increasing teachers' understanding of mathematics and its current applications. Many of the programs focused on problem solving, consumer mathematics, and the use of calculators, with the collaborative playing an active role in promoting the use of calculators in the district's mathematics curriculum. Programs offered over the five-year period included seminars in advanced technologies, workshops, and participation in the Problem-Solving Infusion Project and in the Cleveland Teachers' Internship Program. The dinner symposia, discussed at the beginning of the previous section, also provided opportunities for teachers to update their knowledge of current topics in mathematics education. Many of these programs were conducted collaboratively with an institution of higher education, a business, or industry.

Seminars in Advanced Technologies at Lorain County Community College

In the spring of 1985, 1986, and 1987, Lorain County Community College's High Technology Center offered week-long courses that focused on mathematics in high technology industries. The five-day programs were designed to broaden the experience of junior and senior high school mathematics teachers through participation in a series of workshops on advanced technologies. A total of 33 collaborative teachers participated in the series of four seminars, with participants receiving continuing education credits, tuition, mileage, and lunch allowances, as well as a $100 stipend. At the workshops, teachers were instructed in the basic concepts of new technologies and made aware of the integral part that mathematics plays in each.

Oberlin Problem-Solving Workshops and Seminars

The collaborative worked cooperatively with Oberlin College to offer teachers summer workshops on problem solving. In June, 1986, six secondary school mathematics teachers received collaborative funding to attend a problem-solving workshop at Oberlin College designed to sharpen teachers' skills, to help them build a problem-solving library, and to guide them in preparing a plan for classroom implementation. The workshop was led by Dr. Rudd Crawford, who is a mathematics teacher at Oberlin High School, the director of the SATELLA Project in problem solving, and an instructor at Oberlin College.

In addition to the summer workshop, Oberlin College sponsored six weekend seminars on problem solving during the 1986-87 school year. Each session included a Friday dinner meeting and a Saturday breakfast meeting with the full program lasting into the afternoon on Saturday. Fifteen teachers were eligible to participate in each seminar. Places not filled by CPS teachers were filled by teachers from neighboring districts; the opportunity provided for the teachers to mix with colleagues from outside the local system added an important dimension to the activity. By the end of 1986, one-quarter of the collaborative's target population had taken part in the summer problem-solving workshop or weekend seminars. Teachers who were selected to participate in the sessions wrote problems that were added to the set of problems that had been distributed at a district-sponsored workshop on problem-solving held in August, 1986. As a result of the enthusiasm generated by these sessions, a Problem Solving Standing Committee comprised of Cleveland teachers was formed to collect data about the use of the problems and to develop and distribute additional problems.

Collaborative Workshops

The collaborative sponsored a variety of workshops over the five-year period, many of which were conducted by collaborative teachers.

Calculator Workshop. In 1986, the collaborative initiated an inservice workshop for intermediate mathematics teachers to ensure that they were comfortable working with calculators and to integrate them into the curriculum. Significantly, it was the first systematic calculator instruction to be introduced in the Cleveland Public Schools. Fifty-one intermediate teachers attended. The plan for incorporating calculators into the district's curriculum illustrates how the collaborative served as a catalyst: the Cleveland Education Fund contributed $5 000 to the cost of calculator materials; the Cleveland Public Schools paid teachers for their attendance at the inservice training sessions; the State of Ohio underwrote the cost of three national trainers, a facility, and refreshments; and the collaborative assisted in developing, disseminating, and implementing new units and activities that were created as a result of the inservice training.

1988-89 Workshop Series The collaborative sponsored four workshops during the 1988-89 school year. The first workshop, held in August, 1988, focused on topics in fourth-year high school mathematics and provided instruction in software developed by the North Carolina School of Science and Mathematics (NCSSM). The workshop, which was attended by 10 collaborative teachers, was presented by 2 of the 3 teachers who had participated in a program on fourth-year college preparatory mathematics at NCSSM during the summer of 1987. The second workshop, held in September, 1988, was designed to provide teachers with hands-on experience with the computerized gradebook. Participation was limited to the first 20 teachers to apply. In November, 1988, the collaborative sponsored a workshop featuring David Johnson, chairman of the Mathematics Department at Nicolet High School in suburban Milwaukee and author of the books, *Every Minute Counts: Making Sense of Your Math Class Work* (1982) and *Making*

Minutes Count Even More (1986). Mr. Johnson provided tips on the art of questioning, on efficient homework correction, and a practical notebook system, as well as suggestions for daily organizational techniques. Approximately 60 people attended, including 8 Advisory Board members. In February, 1989, the collaborative sponsored a workshop on the graphing calculator that was conducted by five collaborative teachers. The workshop was attended by 26 mathematics teachers and 3 science teachers, each of whom received a graphing calculator.

"For Teachers By Teachers" Workshop. To launch the 1989-90 school year, in August, 1989, the collaborative sponsored a workshop, "For Teachers By Teachers." Participants had the opportunity to preregister for two of six potential sessions. At the workshop, four of the six sessions were presented by Cleveland teachers: Computer Graphing and the Electronic Chalkboard, NSF Problem-Solving, the Computer Bulletin Board, and Geometry Fair Ideas. In addition to attending two sessions, teachers had the opportunity to view displays that included materials about the Cleveland Education Fund small-grants program, applications for professional conferences, and materials by Creative Publications. The workshop, which was attended by approximately 80 teachers, concluded with a luncheon address on the parallel issues of equity and alternative assessment methods by Professor Genevieve Knight of Coppin State College in Baltimore, Maryland.

Problem-Solving Infusion Project

In November, 1988, the Cleveland Education Fund received a four-year $400,000 grant from the National Science Foundation to develop a program to infuse problem solving into the seventh-grade and eighth-grade mathematics curriculum. Eleven teachers volunteered to consult on the project during the year and to meet with Dr. Crawford of Oberlin College twice a month to discuss problems and their students' reactions to them. The problem worksheets that were developed were collected in a notebook that was made available to other teachers.

Industry Internships

The Cleveland Teachers' Internship Program (CTIP) was established in 1980 to provide teachers with hands-on experience involving the mathematics used daily in business and industry. The program organizes summer work placements for teachers in area businesses or industrial laboratories for which teachers receive a stipend. In addition to working at the corporation, teachers attend approximately six afternoon seminars over the course of the summer and prepare a project for their own classrooms. In the summer of 1985, C^{2}ME coordinated 11 placements in industry and in a parallel effort, identified one internship at Cleveland State University. In the summer of 1986, seven teachers, many of whom had participated in the 1985 program, had internships. Seven mathematics teachers participated in the internship program during the summer of 1987 and eight intermediate and secondary mathematics teachers in the summer of 1988. Prior to C^{2}ME, only one Cleveland Public School Mathematics teacher had been placed through CTIP.

Teacher Professionalism

A primary focus of the Cleveland Mathematics Collaborative for Mathematics Education is to enhance the professional growth of teachers. The collaborative has provided mathematics teachers with opportunities and experiences not previously available to them to heighten their sense of professionalism. The collaborative awarded travel grants to enable teachers to participate in meetings of professional organizations, many for the first time; assisted teachers in applying for grants under the Small Grants Program available through the Cleveland Education Fund; arranged for Teacher Scholarships from John

Carroll University; and, through events such as the Retirement Dinners, helped teachers to receive recognition for their service. The collaborative has encouraged teachers to take an active role in the development of the district's mathematics curriculum, assuming a new level of responsibility. Teachers have also increased their participation in professional organizations, assuming leadership roles in the Greater Cleveland Council of Teachers of Mathematics and making presentations at the annual conferences of the Ohio Council of Teachers of Mathematics. The Cleveland Mathematics Teachers' Resource Center, which provides a meeting place teachers can call their own, has also contributed to the strong professional identity among Cleveland mathematics teachers.

The collaborative served as a catalyst, promoting teachers' participation in important professional activities, including curriculum development and teacher inservice training. As a result, teachers are receiving recognition and assuming responsibilities they had not experienced previously. When, for example, the Teacher Advisory Board suggested that a consumer mathematics course be developed, the school district organized a committee of five teachers to work over the summer to develop the curriculum. Teachers have been involved in creating curricular materials, in many cases drawing on input from university and industrial mathematics. Eleven middle school teachers, for example, worked as consultants on the Problem-Solving Infusion Project, helping to develop problems that require visual thinking, and processing information from visual to verbal and back again. The problems that they developed were made available to other teachers through the Cleveland Mathematics Teachers' Resource Center. Between January and March, 1989, seven mathematics teachers met regularly with nine science teachers to develop curriculum as part of the AIMS (Activities that Integrate Mathematics and Science) program. The program is jointly sponsored by the C²ME and the Cleveland Science Collaborative. Following the 1986 Oberlin Problem-Solving Workshop, the collaborative paid the six CPS teachers who participated, enabling them to spend two weeks organizing and further developing the problem-solving materials, as well as planning two one-day workshops on problem solving for CPS mathematics teachers. The workshops, which were held in August, 1986, were sponsored by the Cleveland Public Schools and attended by a total of 137 teachers of Grades 7-12. In 1986, the CPS mathematics supervisor formed a committee of 23 teachers to review and revise the pupil performance objectives and to work on developing midterm examinations to be administered in each school. Three collaborative teachers, after participating in a summer training session at the North Carolina School of Science and Mathematics, acquired a small grant from the Cleveland Education Fund to enable them to pilot-test the materials developed at the NCSSM for fourth-year college preparatory mathematics. These teachers conducted a workshop for Cleveland Public School teachers during the summer of 1988.

Travel Grants

C²ME has committed itself to increasing the attendance of Cleveland Public School secondary mathematics teachers at professional meetings, since their history of low attendance was seen as an impediment to their professional development. As part of its efforts to promote teacher participation in professional meetings, the collaborative awarded funds to support teachers' attendance at a variety of regional and national conferences and at meetings of professional organizations. The collaborative, which awarded 128 travel grants during the five-year period, had difficulty in getting the district to release teachers to participate in professional meetings. Most often, teachers had to take personal leave with pay, and substitute teachers were provided through the CPS mathematics supervisor's general fund. Among the events for which teachers received collaborative funding were the 1989 NCTM Northeastern Regional Conference in Philadelphia; the 1987, 1988, 1989, and 1990 Annual Meetings of the Ohio Council of Teachers of Mathematics Conference; the 1988, 1989, 1990 Annual Meetings of the National Council of Teachers of Mathematics (NCTM); the Region I Workshop, Making Mathematics Work for Minorities, in Chicago in 1989, which focused on reversing long-standing patterns of underachievement and underrepresentation of women and minorities in the mathematical sciences; the 1986 and 1987 Conferences on Computers in Secondary School Mathematics at Phillips Exeter Academy; and a Conference on Educational Collaboratives in 1986.

In addition to financing teachers' travel, the collaborative also arranged funding for district mathematics supervisor Bill Bauer to attend the annual meeting of the National Conference of Supervisors of Mathematics in 1987 and obtained funds that enabled him and Rudd Crawford to attend the Harvard Regional Mathematics Network Information session. The information they received was helpful in writing a proposal to NSF to finance the Problem-Solving Infusion Project.

Small Grants Program

The collaborative has made a concerted effort to encourage teachers to apply for grants from the Small Grants Program of the Cleveland Education Fund. The collaborative held two information meetings for mathematics teachers in 1986 to explain the philosophy of the program and distributed a booklet about the program to all mathematics teachers. The collaborative also provided consultation and assistance to mathematics teachers who were interested in applying for grants.

Between the 1984-85 and 1989-90 school years, the Cleveland Education Fund awarded a total of 79 Small Grants for mathematics-related projects. Prior to C^2ME's involvement, only one of the grants had been received by a Cleveland Public School mathematics teacher. Eight grants were awarded during 1984-85 and seven during 1985-86, totaling $6 170. The maximum amount for a single grant is $500. Ten grants, totaling $4 602, were awarded during 1986-87. In 1987-88, 22 grants were awarded to mathematics-related projects on the intermediate and high school levels and 23 in 1988-89. The grants awarded between 1987-90 averaged $430. Of the 19 grants awarded for mathematics projects in 1989-90, 11 were at the elementary level, 4 at the intermediate level, and 4 at the high school level. Projects included Evaluation and Measurement, Motivation with Manipulatives, Math Motivators and Manipulatives, The IBM *Mathematics Exploration Toolkit*, Informal Geometry, Hands-On Magical Math, and a project by an intermediate school mathematics teacher to implement a Math Lab.

Teacher Scholarships

One of the goals of the collaborative was to provide opportunities for teachers to pursue their individual study of mathematics. As part of its commitment to the C^2ME, the Department of Mathematics at John Carroll University offered scholarships to mathematics teachers in the Cleveland Public Schools. Scholarships cover tuition for university mathematics courses, ranging from introductory calculus and statistics to graduate courses in the department's Master of Arts and Master of Science programs. One award was made for the summer of 1985, two for 1986, one for the summer of 1987, two for the summer of 1989, and one for the summer of 1990.

End-of-Year Retirement Dinners

The collaborative initiated annual end-of-year dinners to honor retiring mathematics teachers at the end of the 1986-87 school year. The dinner held in June, 1987, in honor of the 11 mathematics teachers retiring from the Cleveland Public Schools was the first in people's memory to recognize anyone for service to the school system. The dinner was attended by 35 teachers. The second dinner, held in June, 1988, was attended by more than 90 teachers. At the dinner, Frank Demana and Alan Osborne of Ohio State University, along with several teachers, presented an overview of the calculator project being implemented in the intermediate schools. The third dinner, held in June, 1989, was attended by more than

75 teachers and C^2ME staff. At the dinner, Bill Bauer presented a slide show, recounted the teaching history of the retirees, and presented each of them with a gift.

Teacher Leadership

The collaborative placed a high priority on teachers' involvement very early in its development, so that over the years a strong core of active teachers in professional activities has emerged. Through their participation on the Advisory Board and its standing committees, teachers have assumed leadership roles. In addition, the collaborative has been successful in encouraging teachers to accept collaborative responsibilities that are typically assigned to staff in other collaboratives, such as editing the collaborative's newsletter. Teachers also took the initiative in planning a professional day for a citywide gathering of mathematics teachers. The Teacher Advisory Group had hoped that the school district would plan a district-wide inservice in the fall of 1989, but when it appeared that this would not occur, teachers organized the workshop. Seven teachers met with the CPS mathematics supervisor in the summer of 1989 to plan the program, which was appropriately named, "For Teachers By Teachers." Not only did the teachers plan the workshop, but the four small-group presentations were made by collaborative teachers.

Teachers also demonstrated leadership within their mathematics departments. During the 1989-90 school year, the collaborative sponsored a district-wide competition, The Model Mathematics Project, inviting high schools to submit proposals for grants of \$50 000 to \$75 000 to develop a program to implement the major principles of the NCTM *Curriculum and Evaluation Standards for School Mathematics (1989).* The proposals required a four-year commitment from the high school. Two schools were to be selected to receive four-year funding, beginning in the 1990-91 school year. The staff at the Cleveland Education Fund was available to provide guidance, focus, and support to the schools as they prepared their proposals. The two winning schools, John Adams and Glenville High Schools, were publicly recognized at the May 1990 meeting of the C^2ME Advisory Board. The focus of the Glenville proposal focused on developing its mathematics teachers into a team of specialists by promoting experimentation with alternative presentation styles, tools, and evaluation strategies. The teachers at John Adams will use the grant to continue to rewrite the mathematics program and to upgrade courses. They are experimenting with calculators, computer demonstrations, manipulatives and cooperative learning, and alternative methods of assessment. To secure financial support for the three other finalist schools, the Cleveland Education Fund submitted a proposal to the NSF. In further support of the Model Mathematics Project, the collaborative received \$10 000 in funding through a UMC Outreach Action Grant. The funds will be used to assist teachers in the two schools in their efforts to implement new assessment strategies.

THE IMPACT OF THE UMC PROJECT IN PERSPECTIVE

Cleveland was one of the 11 original collaboratives. Many of its activities and achievements are comparable to those of the other sites. In reflecting on the UMC project as a whole, it seems apparent that the collaboratives have made a major impact on the professional lives of mathematics teachers in inner-city schools (Webb, Pittelman, Sapienza, Romberg, Pitman, & Middleton, 1991a). The primary goal of the UMC project was to enhance the professional lives of mathematics teachers in inner-city schools, as articulated by a Ford Foundation report in 1987: "By fostering colleagueship among mathematicians and increasing the human and financial resources available to teachers, the projects [sought] to reduce teachers' isolation, to boost their professional enthusiasm, to enhance both their receptivity to new ideas and their capacity to discriminate among them, and to encourage resourcefulness in their teaching." In assessing the impact of the project in relation to its intent, it is important to consider the reduction in teacher isolation, enhanced professional enthusiasm, teacher awareness of and receptivity to new ideas, and the development of evaluation and critical reflection skills in teaching.

There are approximately 3 000 high school mathematics teachers at the 11 collaborative sites. Of these, about 600, or 20 per cent, have become frequent participants in collaborative activities at their site. Another 1 100 or more teachers have participated in a collaborative in some way -- that is, well over half of the mathematics teachers in participating districts have been reached by collaborative activities. Two of the collaboratives, Pittsburgh and Cleveland, have reached essentially all of the high school mathematics teachers in their respective districts. By the end of 1989-90 school year, 9 of the 11 collaboratives had expanded their target audience to teachers of mathematics in middle schools. Two of the nine, San Francisco and Memphis, have included elementary teachers. In San Francisco, this move increased the collaborative's potential population from approximately 230 high school mathematics teachers to about 1 500 elementary, middle school, and high school teachers. Over 400 San Francisco teachers attended a spring mathematics conference sponsored by the collaborative. The estimated number of teachers who have directly participated in at least one collaborative-sponsored activity across all of the original collaborative sites approaches 2 000, including high school mathematics teachers, middle school mathematics teachers, and elementary teachers.

In addition to the fact that the collaborative has had a direct impact on a significant number of mathematics teachers, at some sites those active in the collaborative are functioning as resources to other teachers. This represents a ripple effect that distributes the impact of the collaborative beyond those immediately involved. In New Orleans, the mathematics supervisor called on collaborative teachers who had received professional development experiences through the collaborative to lead Title II--financed workshops presented for other district teachers. While information is not available on the full extent of these related effects, in terms of sheer numbers, we estimate that the UMC project has been successful in reaching two-thirds of the potential number of high school mathematics teachers in collaborative districts.

Although the impact on students was not documented, it should be noted that the number of students who could be potentially reached by a single collaborative teacher magnifies the impact of the collaborative many-fold. In some of the urban districts, mathematics teachers have over 150 students in classes over the course of a day. Thus, through the 2 000 teachers who have had some involvement in collaborative events, it can be presumed that nearly a quarter of a million students have experienced benefits of their teachers' collaborative involvement.

Teacher Isolation

From the beginning of the UMC project, teacher isolation was identified as a reality. Teachers generally knew only a small number of other teachers in their district. In some schools, teachers did not know all of the mathematics teachers in their own department. It could not be assumed that the mathematics department at a given school met regularly; in some schools, the only time teachers met each other was informally, during the 20- or 30-minute lunch period. Many teachers had never attended a regional or national mathematics teachers' professional meeting. In some of the districts, teachers had never met, let alone had access to, the mathematics supervisor, nor had they ever had contact with mathematicians in the business and higher education communities.

The Problem

The problem of teacher isolation is perpetuated by several factors. One is that the conditions of teaching in large urban school districts creates barriers that make it difficult for teachers to interact with each other. The physical structure of large inner-city school buildings, the dispersion of mathematics teachers in all parts of the building, the lack of a department office or other central meeting place, and responsibility for monitoring the halls or cafeteria during non-classroom time all tend to prevent teachers from interacting with each other. Many of the school districts depend on one mathematics supervisor.

Because of the physical size of the districts in terms of the number of teachers, number of students, and the distance among the schools, mathematics supervisors often rely more on sending written directives than on personal interaction with teachers.

A second factor contributing to teacher isolation relates to the nature of teaching. Teachers spend nearly all of their professional time with their students. The results of the Survey on Teacher Professionalism administered in 1986 to 576 collaborative teachers (see Romberg et al., 1988) indicated that an important reason why collaborative teachers became teachers was because they enjoyed being with students. Having to provide instruction for 100 to 150 or more students each day compels teachers to focus their efforts on their responsibilities to their students. This leaves little time and energy for doing much else. The demands of teaching -- remaining alert to the needs of the individual students, maintaining order, and being physically active nearly all day--are exhausting. Because of the very nature of teaching, teachers tend to direct less attention to other teachers and spend most of their time oriented to students.

A third factor contributing to teacher isolation is the absence of a sense of professionalism. Many teachers do not seem to feel a responsibility to the profession as a whole, nor do they believe that the time and energy spent participating in a professional group is worth the effort.

The Reduction of Teacher Isolation

The variety of approaches to collaboration that have been implemented have reduced teacher isolation in most of the collaborative sites. One important change has been the development of new alliances between mathematics supervisors and teachers. This has occurred in fact in most of the collaboratives. The greatest interaction between the teachers and mathematics supervisors has taken place in districts in which the collaborative has actively involved the supervisors in the planning process and been sensitive to the importance of building upon the supervisors' programs. The collaboratives have developed into active support systems for supervisors, a development which has resulted in supervisors turning more to teachers for input. Finally as indicated earlier, the interaction with the mathematics supervisors led groups of teachers in many districts to become more active in their district mathematics education program.

In Cleveland, for example, the mathematics supervisor now works with several groups of teachers to further the mathematics program in the public schools. The supervisor depends upon the teachers to provide resources for programs such as the Mathematics Teachers' Resource Center, the problem-solving bulletin board, the Problem-Solving Infusion Project, and a calculator project.

In Pittsburgh, monthly meetings between the Instructional Teacher Leaders and the district's mathematics director have resulted in an on-going dialogue. In Los Angeles, although the mathematics supervisor was not very involved at the beginning of the collaborative, he became active. When he formed a district mathematics committee, he included mathematics teachers who had come to his attention through the collaborative.

In some districts, systemic changes were made that provided collaborative teachers with special privileges. For example, the Memphis Public Schools have given collaborative teachers additional release days to engage in professional activities. It is clear that the UMC project has been effective in reducing teacher isolation through the establishment of a stronger relationship between mathematics supervisors and the teachers and through including teachers more in the curriculum decision-making process.

Change has been less evident in those districts in which neither the mathematics supervisors nor the administration have been an integral part of the process. In Durham, for example, the mathematics supervisors have been kept informed, but have not taken as active role in the planning process. In the Twin Cities, the mathematics supervisors have been active, but the districts have demonstrated only limited support for the collaborative. As a consequence, there has not been any structural change in these districts. In fact, in one district the mathematics supervisor's time was reduced to 60 per cent.

A second factor that has acted to reduce teacher isolation is the collaboratives' efforts to develop an expanded notion of professionalism. The collaboratives have given teachers greater access to professional experiences by providing professional development grants, informing them of available opportunities, enabling them to meet with professional groups outside their schools and districts, and providing opportunities for them to be workshop leaders. For some teachers, interaction with a larger professional community and their heightened awareness that they share a professional commitment with colleagues across the nation has helped to renew their interest in teaching. For teachers in New Orleans who attended the 1989 UMC Teacher Leadership Workshop in Newton, Massachusetts, the recognition of what teachers in other collaboratives were accomplishing provided the impetus to make changes in their own district. When they returned to New O· ·ans, they initiated the restructuring of their Teachers' Council into the Leadership Council and began developing strategies for influencing policy decisions. As a result, a collaborative teacher presented the Leadership Council's position at a school board meeting on an issue in opposition to a stand the district administration was supporting. In Cleveland, mathematics teachers chartered a bus to attend the annual meeting of the state mathematics teachers, whereas previously only a handful had attended. Through increasing teachers' involvement in professional meetings and activities, the UMC has expanded the reference group from which teachers can receive both information and support.

In some schools the mathematics department has become a cohesive group that meets regularly. But this is certainly not true in all districts or high schools. Some collaboratives have developed specific incentives to encourage mathematics departments to become more functional and to increase teacher interaction. This has been most apparent in Los Angeles in its new departmental planning process, in San Francisco where the collaborative implemented an adaptation of Los Angeles departmental model, in San Diego where collaborative administrators initiated departmental meetings, and in Cleveland through the Model Mathematics Project. As one Los Angeles teacher reported, "Our department is now beginning to focus together on problems. The process is slow but teachers are becoming less isolated."

The collaborative coordinator for New Orleans -- a collaborative that did not focus on departmental change -- noted that this was one element of their program that could have been improved. Individual teachers in New Orleans have become involved in collaborative activities, but the departmental units essentially remain unchanged. Within the same school there will be teachers who are very active in the collaborative and others who have very little awareness of the collaborative. In a few instances, pairs or small groups of teachers within a school have been motivated by collaborative experiences to work more cooperatively with each other in their teaching. While in these schools departmental dynamics may have remained the same, teachers are now working together to use computer software with their students and to plan instruction for their classes. The collaborative has influenced changes in the functioning of a department when department dynamics have been a direct focus of the collaborative. When this has not been the case, teachers have forged their own working relationships, even though the departmental dynamics remained untouched.

A key factor in the reduction of teacher isolation has been the expansion of teacher networks. Prior to the advent of the collaboratives, district mathematics teachers had little opportunity to get to know each other. While many school districts had all-district inservices the week before the school year began, and some held a mid-year inservice, teachers had a tendency to sit with others they already knew. All of the collaboratives initiated gatherings for mathematics teachers that, at least in part, were designed to acquaint mathematics teachers with other mathematics teachers. Through these functions, teachers began to identify with the la.˜e group of district mathematics teachers. Most of these large group gatherings had other than purely social purposes: in San Francisco, for example, teachers heard a nobel laureate speak and in St. Louis, foreign educators presented programs on mathematics education in their countries. The socialization function that the collaboratives have served has been important. A business associate active in the Cleveland collaborative felt that informal gatherings were crucial because people get to know each other in informal settings more readily than in meetings. The collaboratives also have been able to provide amenities, such as refreshments for meetings, that districts are often prohibited from doing. For some collaboratives, in fact, refreshments have become a trademark. In Pittsburgh, teachers know that it is a collaborative event when refreshments are served.

Many collaboratives, especially in the initial years, made networking a primary objective. The Durham Mathematics Council held five or six meetings during the school year for teachers who were teaching a particular course. During the development stages of the Philadelphia collaborative, the coordinator viewed herself as an in-school collaborator who could link together teachers who had common needs. Through socializing, networking, working together on projects, and other professional experiences, mathematics teachers began to draw on each other as resources to a greater extent than they did before the existence of the collaborative. In addition, they are beginning to feel more confident in their teaching. As teachers have gotten to know each other and have the opportunity to communicate and share with their peers, some have become more confident and more willing to try new approaches, such as cooperative learning, in their classrooms. Teachers have indicated that before the existence of the collaborative, they did not know whether what they were doing in class had validity. In talking with other teachers, they have received reinforcement for what they do and the support to make changes. A middle school teacher from St. Paul who has been a frequent collaborative participant put it this way, "I do not feel alone in this job as I have at some times in the past. I use many more innovative ideas [in my daily teaching] and try more new methods that I acquired either from collaborative members or at collaborative sponsored talks and workshops." A frequent collaborative participant from Cleveland noted that one of the most significant changes attributed to the collaborative has been creating "a feeling of togetherness and sharing among the math teachers in our district." A Memphis teacher reflected on the impact of the collaborative, "Personally the most significant change I attribute to the collaborative is that when I step into my classroom, I do not feel alone. I am more keenly aware, than ever before, that there are many others doing what I am doing . . . . Most importantly -- if I feel the need for assistance I have a much larger network of *mathematics* teachers that I may call upon." Comments such as these are made by teachers at each site, indicating that the collaboratives have brought mathematics teachers together in ways they have not experienced before.

Teacher isolation is being reduced through the collaboratives and the larger UMC organization as a result of teachers forging new and stronger relations with those in their school, their district, and across the nation. The collaboratives also have had some success in reducing the gap in understanding between mathematics teachers and those in business and higher education. Collaboratives have sponsored many events that have included teachers and representatives from business and higher education, and over half of the collaboratives have organized site visits for teachers to enable them to experience the business or corporate workplace. Nearly half of the collaboratives have offered summer internships, or have been associated with an internship program that provided summer opportunities for mathematics teachers to work in businesses. All of the collaboratives have representatives from business and higher education serving on advisory boards. In Cleveland, Memphis, Philadelphia, San Diego, San Francisco, and the Twin Cities, faculty from local colleges and universities have served as valuable resources in giving workshops and institutes.

A few collaboratives have been able to develop more unique relationships among business, higher education, and teachers. In Cleveland, where there has been a history of strong business support in the community, business and higher education members of the collaborative's Advisory Board formed the Advocacy Committee. This group actively developed and put into operation a model mathematics project to support mathematics departments in creating innovative mathematics programs aligned with the principles of the NCTM *Curriculum and Evaluation Standards (1989)*. The concept of advocacy, as demonstrated in Cleveland, has led to a mature state of collaboration that extends across the sectors. Through the Advocacy Committee, those from business and higher education have become much more knowledgeable about the condition of teaching in inner city schools. Cleveland teachers have a strong sense of the support from these sectors. In this environment, the Cleveland Public Education Fund has been successful in obtaining NSF funding to encourage innovation by mathematics departments. The efforts by business community members to develop a plan to support mathematics education in the public schools have not been as prominent in other collaboratives. The Cleveland collaborative had set the stage for this level of support, however because throughout the history of the collaborative, the district mathematics supervisor and the teachers had kept the Advisory Board informed of new innovations in mathematics education, including the principles of the NCTM *Curriculum and Evaluation Standards*. The Cleveland advocacy model has proved unique. In the other collaboratives, support from business and higher education generally has taken the form of financial contributions or the commitment of someone's time to a certain function or activity. However, in every case of business sector involvement, one principle was clear: if members of the business and higher education communities are to be committed and willing to give their time, they need to believe that what they are doing is meaningful.

The UMC project has also generated other forms of cross-sector collaboration. In Los Angeles, for example, a team made up of a teacher, a business representative, and a chemistry professor developed and gave a four-part workshop for mathematics teachers as part of the collaborative's +PLUS+ workshop series. Each member of this team contributed his or her expertise for the benefit of other teachers who took the workshop. The professor provided a conceptual understanding of mathematics in the world of science; the engineer presented practical models for applying the ideas; and the teacher distilled these ideas so they would be understandable to high school students. A key factor in the formation of this team is that the teacher asked the university professor to become involved. Because the request came from the teacher, the professor, already over-committed, was willing to participate.

Both the Advocacy Committee in Cleveland and the Los Angeles triad have brought together talents from each sector, more or less on an equal level, to achieve specified goals. Other collaboratives have generated business and higher education involvement by inviting representatives from these sectors to serve on advisory boards, sponsor site visits, mentor an intern, or give presentations. While these forms of collaboration do not lead to structural changes, they do contribute to the exchange of information among the sectors and signify the commitment of the business and higher education communities to the support of teachers.

While all of the collaboratives have made inroads in initiating communication between teachers and members of the business and higher education communities, over the five years of their existence most of these have focused more on the development of interaction among teachers than on communication between teachers and those from business or higher education. One reason for this is that teachers have not always felt that interaction with those in business or higher education is productive. For example, while the site-visit experience has given teachers information that has proven useful in explaining why students should study mathematics, teachers have been less apt to use the information to structure classroom experiences for their students. In preparing for site visits, representatives in industry have had difficulty communicating about the mathematics they use in their work at a level meaningful to teachers. As noted above, successful interactions of this sort require cooperative efforts from all groups in pursuing a common goal. In New Orleans, the collaborative coordinator met with business people prior to the site visit to clarify expectations. And in Cleveland, teachers provided feedback that enabled the company to generate a book of work-related problems for use in the classroom.

Teachers have valued the workshops and institutes sponsored and/or funded by the collaboratives. At first, most of these were presented by representatives from higher education. As the collaboratives have matured, however, a greater number of professional development experiences are being led by teachers. This is an indication that teachers are assuming greater responsibility for providing resources to other teachers.

The Enhancement of Professional Enthusiasm

The collaboratives have increased the enthusiasm teachers have for their profession. On the Survey on Teacher Professionalism (see Middleton *et al.*, 1991) administered in 1990 to teachers in the 11 original collaboratives, 81 per cent (489 of 601 respondents) of the frequent or occasional collaborative participants agreed that the collaborative "had enhanced the professional lives of mathematics teachers." A larger proportion of those who were active than of those who were only occasional participants in the collaboratives strongly agreed that the collaborative had enhanced their professional lives; 42 per cent of the frequent participants strongly agreed, whereas only 16 per cent of the occasional participants did.

A high percentage of collaborative participants, 69 per cent, also indicated that the collaborative has expanded their notion of what it means to be a mathematics teacher. Those who have been most active in the collaborative feel stronger about this effect than do the marginal participants. One-third of the frequent participants, compared to 9 per cent of the occasional participants who responded to the questionnaire, strongly agreed that the collaborative was responsible for expanding their perception of their profession.

A number of teachers have indicated that they have remained in teaching due to the collaborative. As a result of gaining greater support and becoming more involved in mathematics-related activities, these teachers have increased their enthusiasm for teaching in ways that have helped them to transcend the many demands placed on them by their students and the administration. An active collaborative teacher put it this way, "The most significant change in my professional career that can be attributed in part to the collaborative is my desire to continue to teach. Because of the positive experiences I have encountered, teaching became fresh to me again." Some teachers feel that through their collaborative they have become more valued both as teachers and as decision makers. This feeling of importance has helped to increase teachers' enthusiasm for what they do. A Pittsburgh teacher reports that the Pittsburgh Mathematics Collaborative has had a major effect on his perception of teaching, "I have found that my attitude has improved about the decision making [regarding] curriculum items in mathematics. I am more [inclined] to work at curriculum items because my role as a teacher has important influence in curriculum changes."

Collaborative teachers continue to report on the value of networking with other teachers and on the support they gain from such interaction. This collegiality is a major factor in increasing their enthusiasm for teaching. The UMC project has heightened the enthusiasm of mathematics teachers for their own teaching and for their profession. Teachers have gained a renewed sense of being valued by the larger community; they have access to state-of-the-art ideas in mathematics education; and they are being supported by others in their efforts to improve their level of professionalism.

Teacher Awareness of and Receptivity to New Ideas

The UMC project has been instrumental in bringing the national agenda for mathematics education into inner-city districts. This has been achieved by granting teachers funds to attend national meetings, bringing in nationally known speakers, informing teachers of professional opportunities, and conducting workshops on the most current national trends. The collaboratives have fostered the development of highly motivated groups of teachers who have been able to take advantage of and build upon the momentum created by the release of the NCTM *Curriculum and Evaluation Standards* (1989). A Philadelphia teacher, for example, admitted that because of the collaborative, "I paid special attention to the NCTM *Standards* which I would have otherwise ignored." (See Appendix A to the previous chapter.)

A teacher active in the Durham Mathematics Council responded to a question about how the collaborative has increased teacher awareness of the current trends in mathematics education; "We have really studied the *Standards* and tried to implement them. DMC has widened my knowledge of some mathematics areas that I'd not heard of before despite my bachelor's and master's degrees in the field." Other DMC teachers reported learning more about discrete and finite mathematics.

By taking advantage of professional development grants financed through the collaborative, many of the collaborative teachers have attended national meetings and other professional events. Supported by their collaborative, a number of teachers have attended an NCTM annual meeting for the first time. A St. Louis teacher noted the wide experiences that the collaborative has provided, "[I am] more motivated to keep up. I have seen Irwin Hoffman, Jan de Lange, Marilyn Burns, [an] EQUALS Program [presentation], Tom O'Brien, Zal Usiskin, Uri Treisman, Jane Martin and [attended a] Woodrow Wilson Institute. There were just not these choices before the collaborative."

Collaboratives have been successful in helping teachers make sense of the wealth of information and materials that are now available to them. Through workshops, institutes, and publications, the collaboratives have made teachers aware of new materials, methods, and technologies and helped them to set priorities as they face the challenge of mathematics reform. As one Durham Mathematics Council teacher reported, "I have a much better sense of what is important from our workshops and network meetings. DMC is on the cutting edge of mathematics, changes in instruction, and equity. DMC critiques for us and helps separate the wheat from the chaff." In this sense the collaboratives have provided leadership in mathematics reform by helping teachers to sort through the voluminous amount of information to find what can be useful to them. Assisting teachers in this way has been a particular characteristic of collaboratives that are associated with an institution that is itself doing work in mathematics education reform: the Durham Mathematics Council in its association with the North Carolina School of Science and Mathematics; the San Diego Urban Mathematics Collaborative and its association with the Center for Research in Mathematics and Science Education; the Twin Cities Urban Mathematics Collaborative and its association with the University of Minnesota and colleges in the area; and the Cleveland Collaborative for Mathematics Education and its association with various local universities.

All of the collaboratives have provided teachers with experience in using technology (such as computers, software packages, and graphing calculators) in their classrooms. For example, the Philadelphia collaborative, in cooperation with the district, has established a technology conference that has become a yearly event. At this conference, teachers demonstrate to their colleagues how to use certain software or calculators. The participants have time to practice using the equipment, then they take materials back to their classrooms to use with their students.

The UMC project has enabled some teachers to use computers in their classes more extensively. Some of the collaboratives were instrumental in circumventing the local bureaucracy so that teachers could obtain computers for use in their classrooms. It appears that having someone from outside the district request the insulation of a telephone line to hook up a modem, or to get a computer out of storage and into a teacher's classroom, has greatly facilitated the process. One Memphis teacher learned more about using computers with her pre-calculus class when she attended a summer conference in Durham, partially sponsored through UMC. Upon returning to Memphis, the collaborative coordinator helped her circumvent part of the procurement process in order for the district to provide a computer for the teacher's classroom. Her students became so accomplished in using the computer that they were invited to give demonstrations to teachers at conferences on the applications of software.

Many of the teachers who have become active in the collaboratives have responded positively to the introduction of new ideas. A number of teachers have made major changes as the result of encountering new approaches with only minimal encouragement. Two St. Paul teachers, after hearing a talk by Uri Treisman, began to restructure their geometry course to encourage students in seeking help from each other, thus facilitating student-student interaction. Students were also encouraged to ask teachers other than their classroom teacher for help so they would become accustomed to using a variety of resources and less dependent on a single authority. A teacher in the Los Angeles area received support from his department head to teach one period of geometry without a textbook. The encouragement he received and the ideas that he built upon came from a variety of sources, the collaborative being one. The collaborative created an environment in which this teacher was empowered to make a change. Throughout the year, he received encouragement and ideas over the electronic network from teachers and others in the larger UMC network.

In some collaboratives, systemic changes are evident in the new courses being offered in the district curriculum or the formation of groups of teachers making decisions about district curriculum. Teachers in Memphis developed a course for students to take during their senior year as an alternative to Advanced Placement Calculus. In Los Angeles, a teacher tried to persuade the district to institute a finite mathematics course that students could take instead of Advanced Placement Calculus. In Pittsburgh, a problem-solving course aligned with the NCTM *Curriculum and Evaluation Standards* (1989) has replaced the traditional 9th-grade general mathematics course. A Mathematics-In-Applications course that is technology-driven is being offered in Philadelphia to help students fulfill the state graduation requirement of three years of mathematics. The collaborative was instrumental in distributing software among teachers and helping them plan the course.

Collaborative teachers report that the collaborative has indeed made a difference in how they teach mathematics. The on-site observer in each collaborative was asked to interview five or more teachers, three or four times during the year, to indicate what effect of the collaborative on their daily teaching. All but two or three of the teachers reported that the collaborative had some impact on what they do in their classes. A large percentage of them reported being more willing to take risks--a result they attributed to the ideas exchanged in the interaction with other teachers through collaborative activities and to the fact that they have support for trying something new. A junior high school teacher active in the Twin Cities collaborative noted the effects on the collaborative on her daily teaching, "I do not feel alone in this job as I have at some times in the past. I use many more innovative ideas and try more new methods that I acquired either from other collaborative members or at collaborative-sponsored talks and workshops." A Cleveland teacher noted the most significant changes attributed to C^2ME, "Very simply, I have become a risk taker in the classroom. From a professional standpoint, I feel appreciated for the first time. The collaborative has helped create a feeling of togetherness and sharing among the math teachers in our district. This can have only a positive effect on our students." A teacher from San Francisco reported that she was more willing to take risks. As one result, she no longer feels compelled to follow a textbook. "I guess I attribute that largely to our experience at the Exploratorium," she reported. "It took a long time for me to integrate that into my daily teaching, but I learned from it that everything need not be presented in a book."

Many of the nearly 60 teachers interviewed across the collaborative sites felt they were being more innovative in using ideas that they had been exposed to as a result of attending collaborative-sponsored events. Others noted the use of technology as the biggest change in their classes. A few were using manipulatives and cooperative learning more with their students. A junior high school teacher in Cleveland is now using manipulatives and scientific calculators for the first time, resulting in a dramatic change in teaching and learning in the classroom. Another Cleveland teacher has experienced similar changes, "Not just in part, but my whole way of 'being' as a teacher has turned around. I am open to piloting new trends in the classroom, i.e., calculators, problem solving, and manipulatives. I am not at all tied to going page by page through a math textbook and my students are enthused and involved in their math lessons."

Many other stories of teacher interventions could be related. It is very evident that the UMC experience has increased teacher awareness of the current trends in mathematics education. This, reinforced by support from their peers, has given teachers the confidence and the knowledge to make changes. For some teachers, the collaborative experience has affirmed what they have been doing, giving them more confidence in themselves and greater assurance that their students are receiving the instruction that will prepare them for a changing world.

The Development of Evaluation and Critical Reflection Skills in Teaching

All of the collaboratives have provided opportunities for teachers to gain new information and to share ideas with each other. Rarely, however, have these experiences resulted in teachers identifying both the positive and negative aspects of ideas shared, or offering constructive feedback for making improvements. Because the conditions of teaching do not offer teachers the opportunity to reflect critically on what they or other mathematics teachers are doing, it has taken a concerted effort on the part of any individual collaborative to be able to address this issue.

In Pittsburgh, in cooperation with the district's department of mathematics, teachers have been encouraged to pilot ideas so that curriculum decisions can be made on the basis of data and experience rather than on that of opinion alone. When selecting an algebra textbook for the district, a small experiment was conducted using three different books. Student test results were one source of information used to determine the effectiveness of each of the textbooks. The environment in Pittsburgh encouraged two teachers to make changes in their geometry course by participating in a one-week Woodrow Wilson Summer Institute in Geometry. These teachers sought and received permission to pilot a new textbook. The next year other teachers were included in the pilot. The collaborative in Pittsburgh has helped to establish an environment that encourages teachers to pilot new ideas and to gather information on how these ideas work so that rational changes in the system can be implemented. The director of mathematics has been a key person in creating this environment.

There have been numerous instances in the UMC network of teachers piloting new materials--for example, some teachers in the Twin Cities implemented their ideas during the school year, after attending University of Minnesota summer institutes. And teachers in each of the collaboratives have been asked to use materials developed at the North Carolina School of Science and Mathematics. There have, of course, been some missed opportunities, such as when teachers have shared teaching ideas in workshops or conferences without any open discussion of their merits and difficulties. In these situations, most often ideas are accepted at face value with little or no consideration given to whether implementing the idea will further develop students' knowledge of mathematics or help them relate their knowledge of mathematics to other experiences.

Only a few of the collaboratives have held events oriented to encouraging teachers to reflect critically on teaching, on the curriculum, or on some other aspect of teaching. For this to happen, it seems necessary that the collaborative coordinator or director be a driving force. In Los Angeles, the collaborative director helped resolve certain systemic problems so that teachers could visit other schools and observe other teachers presenting lessons. Time for discussion of what the teachers observed was also built into this experience. Sometimes the lesson was videotaped so teachers could share the experience with other teachers in their schools. Throughout the existence of the collaborative in Los Angeles, the importance of reflecting on what has been done and of defining ways to make improvements has been stressed. After each of the +PLUS+ workshop sessions, the presenters gathered over lunch to evaluate the day's sessions and to talk about improvements needed. One component of the +PLUS+ departmental planning process has been to design an evaluation component that will determine what goals and objectives were achieved. Even given this constant concern on the part of the +PLUS+ director for reflection, teachers have difficulty being reflective and critical about their own teaching and the teaching of others.

In general, teachers have resisted the idea of reflecting critically on instruction, particularly on what others do. One reason for this resistance may be that teachers are constantly striving to give positive and supportive feedback to their students. Another is that teachers have not been trained to be critical in a positive way. When teachers talk with other teachers, they tend to want to support the teacher rather than be critical in any way. Routinely, when a collaborative has sponsored an experience for teachers to share ideas with each other, the interaction among the teachers has focused on explaining the ideas without anyone discussing how they might be improved, on what difficulties they present, and on critically evaluating how they might serve to increase students' knowledge of mathematics. In general, the collaboratives have neither created the conditions nor provided activities that help teachers (1) build the skills to reflect productively on their and others' teaching and (2) offer constructive criticism. Finally, within the hierarchical organizational structures of teacher assessment, peer critique is seen as threatening and in conflict with the development of collegiality.

SUMMARY

In summary, the UMC project has had a positive impact in reducing teacher isolation, as well as in increasing professional enthusiasm and enhancing teacher awareness and receptivity to new ideas. The collaboratives have not been as successful in developing teacher evaluation and critical reflection skills.

The greatest response and support still has come through teachers helping other teachers. This has happened in an environment where those from business, higher education, and the district administration have contributed resources and encouragement. The project has increased the awareness of the commitment of teachers and their enthusiasm for what they do on the part of people in business and higher education, although other sectors still do not comprehend fully what teachers face daily. The gap between the different sectors seems to be due to the lack of a common language for talking about the problems teachers face and the defensiveness teachers display about reflecting critically on what they are doing. There also has been some hesitancy by those from the business sector to voice their full opinions or to offer productive suggestions because they have not felt fully a part of the collaborative process and did not want to offend teachers.

Within the district structure, the collaboratives have made mathematics teachers and mathematics education more visible to the administrators. In some sites, the mathematics collaborative is providing the model for content area development. Interaction between teachers and mathematics supervisors has been increased, with some supervisors viewing the collaborative teachers as the ones to turn to when help is needed. As the UMC project has evolved, it has generated an expanded notion of collaboration that has gone beyond individual sites and is now emerging as a cooperative national effort.

QUESTIONS FOR PHASE II

This case study is based on the developmental period for the 11 collaboratives. The information collected describes in detail how the mathematics collaboratives were formed and what issues were overcome. What is less represented in this case study on mathematics reform is the story of what happens to mathematics teachers, their districts, and their collaboratives after the collaborative has matured and become self-sufficient. Critical questions remain on the dynamics of collaboration and mathematics education reform.

1. What are the long-range effects of the collaboratives on teachers and institutions?

2. What models of collaboration have attained a viable structure that maintains the strengths of collaboration?

3. What roles have collaboratives played in mathematics education reform in a site over time?

4. What have been the spin-offs, both positive and negative, from the collaboratives?

5. Have the collaboratives been able to form a national network to give mathematics teachers in inner-cities a voice?

6. How have the collaboratives impacted on the teaching of mathematics to students in inner-city schools?

INFORMATION SOURCE

Information for this case study was synthesized from data collected by the Documentation Project for the Urban Mathematics Collaborative Project from 1985 through June, 1990. Information was received from reports filed monthly by on-site observers; interviews of teachers, school administrators, collaborative staff, business people, and higher educators; large-scale surveys; and case studies that involved one to three teachers at each site.

REFERENCES

Bruckerhoff, C. E. (1991). "Teachers on the Board: A Case Study from the Cleveland Collaborative for Mathematics Education (C^2ME)." In Thomas S. Popkewitz & Sigurjón Mýrdal (Eds.), *Case studies of the Urban Mathematics Collaborative Project: A report to the Ford Foundation* (Program Report 91-3). Madison: Wisconsin Center for Education Research, pp. B1-B36.

Johnson, D. R. (1982). *Every minute counts: Making sense of your math class work.* Palo Alto, CA: D. Seymour Publications.

Johnson, D. R. (1986). *Making minutes count even more.* Palo Alto, CA: D. Seymour Publications.

Middleton, J. A., Pitman, A. J., Webb, N. L., Romberg, T. A., & Pittelman, S. D. (1991). *Mathematics teachers' views about teaching as a profession: Final results of a four-year longitudinal study.* Madison: Wisconsin Center for Education Research.

National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics.* Reston, VA: Author.

Romberg, T. A., Pitman, A., Pittelman, S. D., Webb, N., Fadell, E. M., & Middleton, J. A. (1988). *Mathematics teachers' views about teaching as a profession: An initial assessment.* Madison: Wisconsin Center for Education Research.

Webb, N. L., Pittleman, S. D., Romberg, T. A., Pitman, A. J., Middleton, J. A., Fadell, E. M., & Sapienza, M. (1990). *The urban mathematics collaborative project: Report to the Ford Foundation on the 1988-89 school year* (Program Report 90-1). Madison: Wisconsin Center for Education Research.

Webb, N. L., Pittleman, S. D., Sapienza, M. , Romberg, T. A., Pitman, A. J., & Middleton, J. A. (1991a). *The urban mathematics collaborative project: Report to the Ford Foundation on the 1989-90 school year* (Program Report 91-1). Madison: Wisconsin Center for Education Research.

Webb, N. L., Pittleman, S. D., Romberg, T. A., Pitman, A. J., Reilly, E. M., & Middleton, J. A. (1991b). *Cleveland Collaborative for Mathematics Education (C^2ME) five year report: A final report to the Ford Foundation on the urban mathematics collaborative (umc) project* (Program Report 91-5 CL). Madison: Wisconsin Center for Education Research.

MATHEMATICS ACCESSIBLE THROUGH TECHNOLOGY: *THE VOYAGE OF THE MIMI* AS AN INTERDISCIPLINARY AND TECHNOLOGICALLY-BASED PROGRAM

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INTRODUCTION

In little over a generation, technology devices used in classrooms have expanded from the whirring film projector and manual film-strip viewer to televisions, video recorders, modems, audio recorders, microcomputers, and hand-held calculators. Technology in the mathematics classroom provides video dramatizations of the applications of mathematics, computerized drill-and-practice, electronic spread sheets, computer courseware, complex symbol manipulators, interactive videodiscs, graphing calculators, and many other instructional devices. In concert with its applications in the classroom, technology has become an area of study itself, creating a new body of knowledge for students to acquire. Even with this onslaught of technology, textbooks have remained the major source of information and material in mathematics classes in the United States; worksheets abound, and students spend the greater amount of their study time working short, direct exercises. This is a case study of one project's attempt to break the stranglehold exerted by traditional materials and to develop a technologically rich environment for an interdisciplinary study of science and mathematics in the middle grades.

There have been few developmental efforts to generate instructional materials that integrate the diverse forms of technology that are being used to provide students with an enriched learning environment and to actively engage students in learning science, mathematics, and other content areas. *The Voyage of the Mimi* Project, initiated in 1981, was one of the earliest attempts to do so. Within the context of a scientific exploration of whales on the first voyage and an archeology find on the second voyage, students become involved in working with mathematical ideas as well as experiencing problems from other content areas. Mathematics is not the major focus of the materials, but is integrated with science, social studies, and language arts.

As a case study of mathematics education reform in the United States, *The Voyage of the Mimi* Project offers a study of four critical issues associated with current reform efforts. One issue concerns the learning of mathematics in the context of real situations. The project encouraged students to work with mathematics and technology as scientists would. Students learn mathematics as they carry out scientific investigations and inquiries. This study of *The Voyage of the Mimi* will explore learning content in a real-world context. A second issue concerns the manner in which curriculum materials can be used to provide students with experiences that integrate mathematics with other areas of study. The curriculum that is partitioned among different subject matters has a long history in American schools. *The Voyage of the Mimi* Project worked to remove these partitions between science and mathematics. Problems related to making connections between subject matters will be examined. A third issue pertains to the use of technology in the teaching of mathematics. Since this was one of the earliest projects that worked with multimedia materials, study of *The Voyage of the Mimi* project affords the opportunity to understand how such a project adapts to rapid changes in technology. This interdisciplinary approach to learning science, mathematics, and technology also offers an opportunity to examine the ways in which resources in schools can shape a project in the midst of barriers and beliefs that work to limit innovation. Finally, because *The Voyage of the Mimi* is one of the earliest projects of its kind, an important issue in this case study concerns the extent to which this multi-million dollar project has influenced the development of other technology-based educational projects. As a case study of mathematics education reform, the project study suggests that the learning of mathematics in isolation is less important than understanding the relationships between science and mathematics, between the different uses of media, and between the Mimi approach and other applications of technology in education.

Our study of *The Voyage of the Mimi* Project also provides a glimpse into how governmental agencies fund innovative efforts. Spanning the decade of the 1980s, it opens an opportunity to reflect on the life cycle of a project and how the priorities of funding sources change over time. Supported primarily by federal funds from two governmental agencies, *The Voyage of the Mimi* Project serves as a rare instance of collaboration between two agencies to finance the development of a precollege education program. The role of government in encouraging innovation is revealed along with the interplay of commercial publishing companies. The two packages, *The Voyage of the Mimi* and *The Second Voyage of the Mimi*, are now available through the commercial company, *WINGS for learning* (TM) (1991). This case study will look at some of the long-term implications of the project--how it adjusted to changing technology, how teachers have used the materials over an extended time period, and how the project, financed primarily by federal funds, became available on the commercial market.

THE ADVANCEMENT OF TECHNOLOGY IN EDUCATION

Technological advances are constantly being introduced into the classroom. The textbook overtook the slate board. The pencil replaced chalk. Films and film strips exposed the post-World War II classroom to sites from all over the world. Overhead projectors supplemented the blackboard, allowing a teacher to face the class while projecting text and graphics on the screen behind her. "Talking heads" began appearing on newly established public broadcasting television channels in the 1950s, lecturing to distant audiences. The advent of portable recorders and cable reduced the scheduling problems of educational television and made video accessible to any classroom at any time. Hand-held calculators, reduced in price in the 1970s, became viable calculating instruments for students, replacing such computing devices as the slide rule. The minicomputer's rise to prominence in the 1970s and 1980s brought a new dimension to instruction. Used first mainly as a delivery system for drill and practice, desk-top computers now are used with a wide variety of courseware that allows students to test conjectures; see visual representations; rotate, enlarge, or shrink images; de elop models; link up with international data bases; and readily retrieve information. New technology on the horizon includes compact (CDROM) and video laser discs, although both are currently more in the experimental--rather than implementation--stage.

Since the advent of television and computers in classrooms, mathematics has been one of the main content areas in which these technologies have been used. Computers and the capacity of calculators for computing make these an obvious asset in teaching mathematics, even though they have not always been perceived as such by teachers. Teachers' varied knowledge of computers, the problem of access to classroom computers, and adequate software have limited the use of computers in mathematics classrooms. A national survey conducted during the 1985-86 school year, a year after the release of *The Voyage of the Mimi* for use in the classroom, indicated that 49 percent of Grades K-6 mathematics teachers, 40 percent of Grades 7-9 mathematics teachers, and 34 percent of Grades 10-12 mathematics teachers used computers in their mathematics classes (Weiss, 1987, pp. 56-58). A lower percentage of science teachers reported using computers -- 25 percent in Grades K-5, 28 percent in Grades 7-9, and 36 percent in Grades 10-12. The major use of computers by K-6 mathematics teachers was for drill and practice. Nearly 80 percent of those who were using computers in their classroom used computers in this way. The next highest rates of use of computers by K-6 teachers were for games (66 percent) and problem solving (38 percent). Only 6 percent of Grade K-6 computer users employed them for testing and evaluation. The applications of computers in the higher grades, 7-12, were more evenly dispersed among several applications--drill and practice (60 percent for Grades 7-9 and 35 percent for Grades 10-12), games (48 percent for Grades 7-9 and 18 percent for Grades 10-12), demonstrating computer use (42 percent for Grades 7-9 and 44 percent for Grades 10-12), learning content (40 percent for Grades 7-9 and 26 percent for Grades 10-12), and problem solving (35 percent for Grades 7-9 and 38 percent for Grades 10-12). Teachers were more apt to use computers in teaching mathematics in elementary courses than in the secondary grades; however, the typical time spent by a student on a computer was less than half an hour per week. The secondary mathematics teachers, in greater percentages than the elementary teachers, had their students use calculators. Of those teaching Grades 10-12, 51 percent reported that their students used calculators, compared to 35 percent of those teaching Grades 7-9 and 14 percent of those teaching Grades K-6. In the mid-1980s, computers and calculators were not widely used in mathematics classes even though there was an increase in the availability of computer software, such as the *Mathematics Exploration Toolkit* (International Business Machines, 1988), *Geometric Supposer* (Yerushalmy & Schwartz, 1985), and *Geometric Sketchpad* (Key Curriculum Press, 1990).

More recent data collected in the 1990 National Assessment of Education Progress (National Center for Education Statistics, 1991) indicate that in four years there has been very little increase in the percentage of mathematics students using computers in their classes. Only 50 percent of Grade 4 students reported ever using a computer in mathematics classes. This was still higher than the 31 percent of Grade 8 students who reported ever using a computer in a mathematics classes, or the 34 percent of Grade 12 students who reported at least using a computer some of the time. A major reason given by teachers for not using computers was difficulty of access.

Television has been used in mathematics classrooms ever since the development of educational television. Lecture courses in mathematics were broadcast from studios at the University of Nebraska in Lincoln to distant parts of the state as early as the 1950s. Television was used to deliver mathematics courses to high schools and to classrooms or homes to enable people to receive college credit. Mathematics educators such as Thomas Romberg and David Wells were both among the early Nebraska television mathematics stars. Television was used in the Madison Project by Robert Davis to show demonstration lessons in the 1960s. The *Patterns of Arithmetic* series for elementary grades was produced at the University of Wisconsin by Henry Van Engen about the same time (1960s) to offer instruction in "modern mathematics." Work on this series, which reached elementary students nationwide, ended in 1972. The 336 fifteen-minute televised lessons of *Patterns of Arithmetic* were transmitted directly to classrooms, reaching 185,000 children in 18 states. The televised lessons were accompanied by teachers' manuals and student workbooks for Grades 1-6.

The work of the Children's Television Workshop (CTW) and its production of *Sesame Street*, first aired in 1969, raised public interest in education television. *Sesame Street* demonstrated that young children could learn numbers, letters, counting, and reading when they viewed muppets and humans interacting in skits and electronic imagery presented with frequent repetitions. Following the success of *Sesame Street*, in the early 1980s the CTW produced *3-2-1 Contact*, a science series for upper elementary students. *Square One TV* (Fisch, Hall, & Esty, 1991), a mathematics series for students 8 to 12 years old, was produced in the latter part of the 1980s to further the reform movement in mathematics education by: encouraging positive attitudes toward mathematics; presenting sound mathematical content in an interesting, accessible, and meaningful manner; and encouraging the use and application of a wide variety of problem-solving processes. This half-hour program, which was broadcast nationally on public education television networks each weekday, used program formats including music videos, magic tricks, and parodies of familiar American television shows.

During the 1980s, the general public became more attuned to viewing scientific programs. In 1988, 84 percent of the American public reported viewing "Nova," or the National Geographic specials regularly or occasionally. This was an increase from 59 percent in 1979, 70 percent in 1983, and 71 percent in 1985 (National Science Board, 1989). The 1990 NAEP results reported that most Grade 8 students in the United States watched at least three hours of television each day. Only a third of the students reported watching two hours or less of television each day (National Center for Education Statistics, 1991). By the end of the 1980s, television was a major pastime for students, and it reached an increasingly high proportion of the public with its scientific programming.

THE VOYAGE OF THE MIMI PROJECT

In 1981, the Bank Street College of Education, located in New York City, responded to a request for proposals issued by the United States Department of Education to develop means of integrating new technology with science education. At the time mathematics was regarded as part of science and technology. The basic concept was to develop a curriculum package that combined the power of existing technology with an integrated science and mathematics program. Two packages were created over the span of the project through the collaboration of the Department of Education, the National Science Foundation, the Bank Street College of Education (a private, nonprofit educational institution), and two commercial publishers, Holt, Rinehart and Winston (a division of CBS, Inc.) and *WINGS for learning*. The first package, *The Voyage of the Mimi*, was published in 1984. The second, *The Second Voyage of the Mimi*, was published in 1988. Central to both packages is the proviso that students experience science, mathematics, and technology in real-world applications. The video series formed the core in both packages. A conscious effort was made to avoid using computers for computer-assisted instruction -- a prevalent use of computers in classrooms at the time -- and to develop computer simulations, games, and laboratories.

The Bank Street College Project in Science and Mathematics, initiated in response to the general concern about the state of science and mathematics education, developed the two *Mimi* packages. A large staff worked on the project, including writers, story/content and other researchers, utilization staff, consultants, and a teacher panel. Nearly 20 teachers served as field-test teachers for the first package.

The Story

Off the coast of New England in the Gulf of Maine, a 58-foot ketch *Mimi* darts through the water. On board a crew of seven perform their duties, each with a specific function. Captain Clement T. Granville directs the sailing of the vessel. His grandson, C. T. Granville, who has come from the midwest to spend the summer with his grandfather, attends to daily chores. Anne Abrams, with a Ph.D. in oceanography, is the chief scientist on board, and is responsible on this research expedition for the study of whales. Her colleague, Ramon Rojas, who has a Ph.D. in marine biology, helps with the design of the study and the recording of data. He is assisted by a senior research assistant, Sally Ruth Cochran, who is deaf and a marine biology major at Gallaudet College. Two teenagers have joined the expedition and offer their expertise: Rachel Fairbanks, a 15-year-old high school student and an experienced sailor, serves as a research assistant; Arthur Spencer, a 16-year-old student from the Bronx, also serves as a research assistant and brings to the endeavor a special interest in electronics and computers.

Drs. Abrams and Rojas have chartered the *Mimi* for a seagoing research expedition to study humpback whales. Over the summer voyage: the crew experiences technical difficulties in the operation of the *Mimi* that require computing the velocity of the vessel in a non-conventional way; whales are studied; scientific instruments are used; the size of the whale population is estimated; the interrelationships between animal behavior and environmental conditions are explored; marine environments are studied; minimum necessities for human survival become explicit; and a scientific breakthrough on fluke patterns is reached. All of these situations are related to the raising of scientific and mathematical questions. Mathematical ideas approached are the measurement of velocity, navigation, data gathering, pattern finding, ratios, and applications.

Students from Grades 4 to 6 (ages 9 to 12) are the main audience targeted by the program, although older students find the materials interesting. "The approach to science instruction taken in these materials is . . . appropriate to the capabilities and interests of elementary school children," (Bank Street College Project in Science and Mathematics, 1985, p. iii). The underlying purpose of the program is to encourage children, who are naturally curious about how the world works, to participate in science and mathematics and to continue to study these areas throughout their school experience. From a more global perspective, the project was designed to increase the technological sophistication of teachers and students in order to meet the needs of, among other things, industries requiring broad technical competence. Several technologies are used in *The Voyage of the Mimi* package "to engage and hold students' interest in some important topics in science and some useful mathematics associated with them" (Bank Street College Project in Science and Mathematics, 1985, p. iii).

A 13-part video series is the central component of the curriculum, with all other instructional materials being derived from this source. The video series is "to provoke and sustain the interest of students by bringing into the classroom some inherently interesting pieces of the real world and by showing some attractive and interesting people engaged in studying them" (Bank Street College Project in Science and Mathematics, 1985, p. iii). Each part of the video series has two 15-minute segments. The first segment dramatizes a scientific adventure story. The 13 parts combined form a serial story line, each episode presenting some mishap, conflict, or challenge. Drama was chosen as a genre because it models roles and attitudes, because research indicated its appeal to youngsters, and because research supported the theory that it delivered information in a form that students could remember. The second series of 15-minute segments depict documentary expeditions to locations at which scientific research of many kinds is being carried out. These segments give an "authentic view" of the real world and what scientists do and what they explore. The great whales were chosen as the object of study in *The Voyage of the Mimi* because of the extent to which human beings are fascinated with these largest creatures on earth and because very little is known about them.

The other components in the package include the Overview Guide, *The Book* (a student's guide), learning modules including computer activities, and wall charts. The Overview Guide is designed to give teachers a synopsis of each episode and expedition, content objectives, vocabulary, program components, questions to ask students, and other information needed to orchestrate the program. The student's guide, *The Book*, gives students an illustrated version of all 26 video segments and suggested activities. *The Book* is self-contained, but it is designed to complement the video series. This printed medium serves as a review for students and as a resource to be used by students absent during the showing of an episode or expedition. The four learning modules -- *Maps and Navigation, Whales and Their Environment, Ecosystems*, and *Introduction to Computing* -- each include a teacher's guide, student's guide, and computer software. The modules give specific instruction and materials for student activities and projects. The use of cooperative learning groups is encouraged. Discussion topics and many of the activities are open-ended, with no correct or incorrect answers. The two wall charts used in the program are an actual navigation chart of the Gulf of Maine, where the *Mimi's* expedition takes place, and a chart of marine mammals of the Western Hemisphere.

Mathematics Within the Materials

Mathematics is embedded in the scientific explorations. Students' activities are designed to engage them in computation, measurement, plotting using nautical measures, data analyses, statistics, proportional reasoning, and problem solving. For example, one student activity in support of the second episode, Setting Sail, is to have students comprehend the length of a humpback whale in relation to the students' heights. Students are to measure the length of a humpback whale shown in a picture, convert the length according to a scale, and then compare the whale's length to their own heights. An activity for the sixth episode, Home Movies, asks students to do the computations to compare the average growth rate of a baby blue whale (5 000 grams/hour) to a baby human (approximately 30 grams/day).

In the *Maps and Navigation* module, students use nautical measures to locate boats on a map, to chart a course for a boat, and to develop a conception of the relationships between speed, time, and distance. Students have to use a compass and identify the bearing from one object to another. One activity engages students in triangulation where two bearings are used to calculate the position of a boat at sea. Parallel lines are employed in this process. Students work with coordinates in establishing the longitude and latitude of objects on a map. Navigation skills are applied in the computer simulation by using instruments and maps to locate one position and then entering direction and speed to reach another position.

Students work with the estimation of populations in the *Ecosystems* module. Population density is computed by finding the ratio between population and area. A practical problem is computing the population density for a classroom aquarium. To estimate a population, 30 marked beans are mixed into a dark-colored jar. Students sample the beans by randomly selecting 10 beans with replacement. After selecting 8 samples the students compute the average number of marked and unmarked beans. These computations are then used to estimate the total number of beans in the jar. The accompanying software engages students in a simulation called *Island Survivors* to enable students to better understand the complex interconnections within an ecosystem. Students read simple graphs that result from their activities, showing the increase or decline in growth of a species on the island. The software is an example of a computer model, which is described to teachers as a real-world application of computer technology. Mathematical equations used to manipulate the variables in the ecosystems are explained to teachers in the module. It is left to the teachers to judge how much of the mathematics needs to be explained to students.

Software is used in the *Whales and Their Environment* module to create a laboratory. An interface board and connectors for sensors are supplied with the module. and are to be attached to the computer. With different sensors, students can measure sound, light, and temperature, and the measurements are displayed on the monitor. Different commands selected from a menu can be used to change the scale (for example, from Fahrenheit to Celsius), change the range of the scale, graph the measure over time, and compare up to five different measurements. Students are asked to read the frequency of sound waves in cycles per second by counting the peaks shown on the monitor in 30 milliseconds. They are then directed to multiply by 33 to estimate the frequency of sound in one second. In another experiment, students measure the speed of sound by computing, both, the distance from speaker to microphone and the time for sound to travel between the two points. Students first calculate the speed of sound in feet per millisecond (the scale used on the computer display) and then convert this to estimate the speed of sound in feet per second.

Developing an understanding of how computers work is a major objective of the *Introduction to Computing* module. Students are told about the different components of computers and how computers use algorithms. Binary numbers are introduced and students are to write the binary representations for different base 10 numbers, and to record their names using the binary alphabet. Pixels are explained and students can do an exercise to see how the resolution of a picture will vary with the density of the dots on a screen. A graduated series of games introduces students to computer concepts. The final part of the module presents students with LOGO commands to move the "turtle" (a cursor shown on the screen) forward or backward over a fixed distance, to rotate the "turtle" left or right a number of degrees, to reuse a specified set of commands, and to repeat a command a specified number of times. Using the software and these commands, students are to draw boxes and create their own designs. Students are able to write their own programs with LOGO to help them better understand how computers work.

Applications of Technology

The program materials for a complete classroom set, available from *WINGS for learning*, cost nearly $1 400 and include 30 student guides. The package is offered in different configurations. In its simplest form, teachers can get the 13 half-hour videotapes (VHS), the overview guide, and students' books without any of the computer software. Three complete packages are available that include the four learning modules -- one with video tapes and software for an *Apple II*, one with videodiscs and software for an *Apple II*, and one with videodiscs and software for a *Macintosh* (only two learning modules are available for *Macintosh* at the current time). One module, *Whales and Their Environment*, includes the Bank Street Laboratory hardware and software that aid in gathering and displaying data about the physical world-- interface board, sound source, sound sensor, light source, light sensor, and two temperature sensors.

The software ranges from games, laboratory experiments with light and sound, and Turtle Graphics (LOGO language) to simulations. Within a module, hands-on and computer activities have been developed with a particular organization. Three computer games in *Maps and Navigation* were designed to provide students with practicing skills and concepts that culminate in doing computer simulation. *The Pirate's Gold* game is used in the *Maps and Navigation* module to help students identify locations by latitude and longitude. The latitude and longitude of the treasure is given to the student. The student then is given a grid with degrees of latitude marked on the vertical axis and degrees of longitude marked on the horizontal axis. The student is to move the cursor over the grid to the location of the treasure. *Lost at Sea*, the second game in the module, directs students to use triangulation to locate a position. In the third game, called *Hurricane!*, students can practice moving a boat over a certain distance at a specified speed. Students are shown a grid similar to the one they used in *Pirate's Gold*, but without specifying the degrees of latitude and longitude. A spot on the grid locates the position of the boat. Students are given a heading and the scale of the grid. By setting the speed and time, students are to move their boat to the shelter of a nearby island before an approaching hurricane strikes. The last software in the module, *Rescue Mission*, is a stimulation requiring students to apply the skills and concepts of navigation they should have practiced in doing activities in the other three games and in the other hands-on activities that form the module. Working in groups, students are to reach a ship as quickly as possible to help free a whale caught in one of her fishing nets. To do this they are given the location of the ship and the endangered whale. Students have to find the location of the ship and give the heading, speed, and time needed to reach it. Students obtain information from a radar screen and by scanning the horizon with binoculars.

The four levels of computer simulations in the *Maps and Navigation* module were designed as a progression requiring increasingly complex navigational skills; they also provide different entry levels into the materials for students. In some of the classes that use the series, students do not do the *Rescue Mission* module, but find the two less complex games quite challenging.

The Second Voyage of the Mimi

First available in 1988, *The Second Voyage of the Mimi* reproduced the philosophy and format of the first voyage in a new adventure story, an underwater archeology project investigating the trading routes of the ancient Maya. The 12 half-hour segments intersperse dramatic episodes with expeditions, as does the first series. Three computer-based learning modules support the video. *Maya Math* helps students explore the Mayan base 20 number system and calendar. The basic approach was intended to encourage discovery and foster in children an orientation toward mathematics as inquiry that would carry over to other areas in the mathematics curriculum. *Sun Lab* introduces students to concepts in astronomy. Students can explore the astronomy of the earth and sun through a simulation/animation program. *Scuba Science*, the third module, employs the Bank Street Laboratory hardware and software with an added pressure sensor in a series of experiments on the physics of pressure, temperature, sound, and light. As with the first

Voyage, The Second Voyage is directed toward offering students a multimedia experience of explorations and inquiry into science and mathematics.

DEVELOPMENT OF THE SERIES

The designers for *The Voyage of the Mimi* series generally came from a wide variety of backgrounds and include educators, classroom teachers, those with educational television experience, software developers, and publishers. The first year of the project was devoted to developing the scripts for the video series and developing prototype software and print material; the second year was spent filming and conducting classroom field tests; and the third year was spent filming the documentaries and completing the software.

The initial intent of the project was to achieve the integration of mathematics and the sciences on three levels: First, science and mathematics curricula were to be integrated in the products and activities of the project. In 1981 such integration was rare. Second, different forms of technology were to be integrated. Third, teachers were to integrate curriculum elements with technology applications into the existing curriculum. These objectives were realized over the 10-year span of the project.

Decisions regarding the choice of technology to be used in the program were based on what was available in the classroom at the time. As a consequence, materials were developed to be used on 1/2" VCRs and Apple IIs with 64 K of memory. As technology in schools became more sophisticated, materials for the second *Voyage* were designed to be used on Apple IIes with 128 K of memory. In 1990, the materials were converted to videodiscs (level 1) on the assumption that a teacher could use one disc to demonstrate materials to the whole class.

The goal of the Bank Street College Project in Science and Mathematics was to create materials that would encourage students to become active participants in the process of scientific investigation and inquiry. One objective was to create a model for classroom use of the new information technologies. A basic assumption was that computer-mediated experiences will help children link concrete and abstract problems in ways otherwise unavailable in the classroom (Martin, 1987, p. 38). The developers were concerned with providing children with concrete and affective experiences before moving on to more abstract activities. Four different types of software were developed to present students with alternative approaches to science and mathematics instruction. A simulation, a data gathering and graphing utility, a programmable environment, and a computer model provided students the opportunity to use computers in the ways scientists and mathematicians actually employ them and, by extension, for the students to experience how computers are actually used in the real world.

Different staff configurations were used in developing the variety of materials in the package. In every case, the most efficient and economic means was used for producing the materials. Some software was developed by issuing subcontracts, some by the Bank Street staff, and some by a combination of these. Games in the LOGO were developed by a programmer employed by Bank Street College. The Technical Education Research Center (TERC), of Cambridge, Massachusetts, was engaged in developing some of the hardware and software, and then a physicist was hired by Bank Street College as a consultant to construct a model around the programs TERC had developed. The development of the video was also the result of a combination of arrangements. A subcontract was given to a production studio, with the project director serving as the executive producer, to create the dramatic series for the first voyage. The documentary expeditions were produced entirely by Bank Street College staff. For the second voyage, all of the video episodes were produced by Bank Street College staff.

Funding

The first grant from the Department of Education, made in the fall of 1981, was for $2.64 million to produce the initial *Voyage of the Mimi* package, including video, software, courseware, and printed text. Overall, the project operated over a period of ten years.

A major issue at the beginning was how to integrate the multiple forms of media to create a product that could be used by schools. The Department of Education issued specifications for deliverables, not for how all the pieces were to fit together. The proposal writing process helped resolve these issues and produced a plan for integrating the different forms of technology.

The initial plan specified that 26 dramatic episodes would be produced. The developed story line specified the *Mimi's* course, north along the coast of Maine and beyond to Nova Scotia. The story then would culminate with the participation in a whale rescue operation. The 26 dramatic episodes that were originally planned had to be reduced to 13, because additional funding was not obtained from corporate funders. A decision was made to supplement the 13 dramatic programs with 13 documentary programs, the latter at one-third of what it would cost to produce the dramatic programs. Although forced into producing documentary programs because of financial limitations, the combination of drama and documentary has been well received. The drama/documentary format is an example of a by-product of the project employed since by other projects.

It is difficult to state precisely the cost of *The Voyage of the Mimi* series. As indicated, the U.S. Department of Education provided $2.64 million toward the cost of the original *Voyage of the Mimi.* Principal funding for *The Second Voyage of the Mimi* was provided jointly by the Department of Education and by the National Science Foundation and totaled $4.5 million. Additional support was provided by the publishers of the two *Voyage* works, Holt, Rinehart & Winston (then a subsidiary of CBS) for *The Voyage of the Mimi*, and *Wings for learning* (a subsidiary of Sunburst Communications, Inc.) for *The Second Voyage*. The support took two forms: advances against future royalties and direct expenditures for the cost of producing and marketing the classroom materials. The extent of these other forms of support cannot be determined. Publishers regard their production and marketing costs as proprietary and will not reveal them; and the contracts between Bank Street College and the publishing companies also required that the royalty arrangements be kept confidential.

Plans were made, but not funded 'o develop a third *Voyage* that would have integrated social studies, mathematics, and science. The third *Voyage* would have been along the Mississippi River. The science focus would have been on the environment. The mathematics used in conjunction with the environmental sciences and made explicit would have involved concepts such as rates of flow and solution concentrations. The history of cultures that have existed along the river would have been studied, from the era of the mound builders to the present, and would take into consideration the way civilization has interacted with the river and its environment. The literature that has been derived from people's experience with the river would have been explored. The third *Voyage* was targeted for the middle school grades; however, for a combination of reasons, funding was not obtained to produce materials for the third *Voyage*. The political atmosphere and priorities at the Department of Education and the National Science Foundation had changed and the priorities for funding in general were different late in the 1980s compared with earlier in the decade.

A second issue in the failure to secure funding for a third *Voyage* was the unavailability of summative evaluation information. The call for evaluation information was not as great in the early 1980s as it was in the latter part of the decade. Gathering summative evaluation was considered in the early years of the project, but the idea was rejected by the developers. One reason offered for this rejection was that the program staff felt that the existing methods available for doing summative evaluation were inappropriate for capturing what the program was trying to do. To develop the methods and instruments needed to do a summative evaluation would divert funds away from developing the instructional materials. At the time an argument was made and accepted by the funding agencies that the program should have time to become established in schools and classrooms before any attempt was made to do summative evaluations. However, in a Catch-22 situation, the governmental funding agencies rejected the idea of the funding for a third *Voyage* in the absence of summative evaluation information on the first two series. The proposal for developing the third *Voyage* included a request for funds to conduct summative evaluations on the first and second voyages while concurrently developing the third series, but this was not persuasive. As a consequence of this and other factors, the third *Voyage* has not been produced. *WINGS for learning* does conduct an annual contest in which students are invited to submit a short story on their own ideas for a third voyage of the *Mimi*.

Development of Materials

The curriculum structure of the first series underwent a number of developmental changes. A considerable amount of thought was given to developing an overriding structure that would unify the ideas across the four classroom learning modules and different forms of media. This was found to be too difficult. Eventually, a concern with the sequence of modules was abandoned. In the end, the modules were not ordered in any particular curriculum sequence. Within the modules, however, classroom lessons are presented in sequence.

Science became the focus for the first series. The mathematics addressed in the series developed out of the science content as opportunities arose to bring out a mathematical idea, such as the use of a grid system. Although the producers had intended to achieve a balance between mathematics and the sciences, the story line carried a greater number of scientific ideas than mathematical ones. A substantial amount of mathematics is used in the materials but is not the main priority. Teachers are given suggestions on mathematics for students to explore and many "hooks" to use in engaging students in mathematical ideas.

Technology

A conscious effort was made to develop materials that could be used on technology already available in a large number of schools. Thus the decision was made to develop software to operate on Apple IIe's and to use the VHS video format. The developers considered the decision to stay with existing technology as very sound, since it would give a greater number of teachers and schools access to the materials than would be the case if an effort were made to ride the wave of technological advances. The publishers provided some pressure, in fact, for sticking with a selected technology configuration and were reluctant to produce materials that were not immediately marketable. Rather than advancing the use of new hardware, however, *The Voyage of the Mimi* advanced the cause of technology in pedagogy by providing computer simulations and models rather than drill and practice.

Now the technology employed in the series is becoming more dated. This is particularly true in those cases in which large states, such as Texas, are providing schools with money to purchase videodisc players, and faster computers with larger memory capacities are becoming more prevalent in classrooms. Efforts are being made to convert the *Mimi* materials to more advanced technology by designing the learning modules to operate on *Macintosh* micro-computers and putting the video series on videodiscs. Bank Street College still retains the copyright on the materials, which puts some constraints on efforts by distributors to up-grade the software and other components.

A means of conducting formative evaluations of the video scripts was in place and comfortable for the developers. The problem of evaluating computer software scripts was a new one for the developers. A model created for evaluating the software was based on one used for instructional television and designed around three questions: Is there understanding of the surface features, such as vocabulary? Can students get around in the program? And, finally, do students learn from using the software? The final package included various topical units joined to one another through a common theme. The computer software and print materials were designed as self-contained modules.

Formative Evaluation

Critical to the development of the materials was the feedback the developers received from formative evaluations. One example serves to illustrate the importance of formative evaluation to the developmental efforts. The *Rescue Mission* is a simulation in which students employ instruments to locate a boat and help free a trapped whale. In an early version of the simulation, students were directed simply to locate a target ship. Once found, the boy students wanted to blow the ship out of the water. The girls were turned off altogether. The situation was then changed to a rescue mission to free a whale caught in a net. This situation fit in well with the original story line of the television program and provided a conclusion, freeing the whale, that was much more appealing to girls while keeping the interest of boys. The evaluation was conducted by personnel at Bank Street, including one person who had the overall responsibility for formative evaluation and another who devoted more time to evaluation of the software.

Other modifications in the materials were based on field test findings. One finding was that teachers' familiarity with computers did not necessarily lead to success in the use of the software. For example, one mathematics teacher with prior experience in teaching children computer programming viewed the navigation software as self-sufficient. This teacher avoided becoming actively involved in monitoring or facilitating students' progress and missed some of the educational objectives. He felt that the software was designed to teach navigation rather than more specific map-reading skills and mathematical concepts of angles, degrees, measurement, and triangulation. Also, a wide variability in students' backgrounds and skills motivated the developers to create multiple-levels of software so that students could have a choice of entry points into the activities.

THE VOYAGE OF THE MIMI IN PRACTICE

The sequence of the two series, *The Voyage of the Mimi* and *The Second Voyage of the Mimi*, perplexed teachers. Even though the two series were developed to be self-contained and to be used in <u>any</u> order, teachers perceived that the two series had to be used in sequence--that is, the first voyage would be used in one grade and then the second voyage would be used in the next grade.

After *The Voyage of the Mimi* was first released, a few studies were done that described how the materials could be used or were being used by teachers. One of the members of the advisory board, Magdalene Lampert, tried the materials with her Grade 5 students and wrote an article about this experience (Lampert, 1985). Some funds were obtained in a separate grant from NSF to look at the issue of teacher training and the effectiveness of this training in helping teachers use the series in their classrooms (Martin, 1987). Another study by Storey and Julyan (1985) for the Harvard Center of Technology reported the results of a series of interviews with teachers about the ease of use of the materials and how the teachers viewed the topic. A few school districts, including some in Texas, have done their own evaluations. Also a video program was produced on both *Voyages* to demonstrate use of the materials for teachers. This video was taped in classrooms in schools in New York.

Range of Implementation of the Two *Voyages*

Materials from the two *Voyages* are used by teachers in all 50 states and in other countries such as Canada, Japan, Korea, The Netherlands, and the West Indies. The video series has been closed-captioned in English and in Spanish. *WINGS for learning* staff estimate that about one million students have used the series. Teachers on the East and West coasts of this country have local motivation to use the two packages because of their proximity to water and connection with sailing. *Mimi* festivals have become popular in some coastal cities where the actual Captain Grandville sails the *Mimi* into port and a set of activities is built around the occasion. Teachers in the heartland of the country are also motivated to use the materials. One teacher in Indiana has students design whales, each with individual flukes. Copies of these whales appear at different times and locations in their school. Students keep logs on these sightings. Students can also use electronic mail to communicate with people on board the *Mimi* at certain times during the year. A quarterly newsletter, *The Mimi Experience*, published by *WINGS for learning*, keeps teachers informed of these special events while also supplying other information. This newsletter includes articles, contests, letters from teachers, questions and answers, and updates on available materials. For example, in the Winter 1991 issue, teachers were informed that through electronic mail, classes from across the nation will be able to communicate to people on board the actual *Mimi* as it travels up the east coast in the Spring of 1991 (*WINGS for learning*, 1991).

An Exemplary Use of *The Voyage of the Mimi* in a Classroom

An example of a way in which a *Voyage of the Mimi* episode provided a context for learning mathematics is reported by Magdalene Lampert (Lampert, 1985). Building upon one of the experiences viewed in the third episode of the series, *On the Shoals*, fifth graders (ages 10 and 11) constructed a formula as a mathematical tool to use in the analysis and solution of a real-life problem. According to Lampert, "The concrete context of the problem enables them [the students] to make reasonable judgments about the correctness and appropriateness of their calculations and also to speculate about a particularly puzzling sort of mathematical relationship: the inverse proportion." Students worked over several days constructing their strategies for relating known quantities to find an unknown. Then the formula's applications were explored with other sets of variables. Another way that the lessons differed from the traditional was that the emphasis was on how numerical patterns could be used and represented rather than on finding an answer.

The lead into the lesson comes from the 15-minute video episode. On the *Mimi's* second day out from Gloucester, Massachusetts, the crew is learning the routines of sailing. Although the *Mimi* is equipped with extensive electronic navigation devices, Captain Granville with the help of Arthur Spencer, the electronics whiz, detects a problem in the electrical system. The knot meter appears to be registering a speed slower than the actual speed of the vessel. The ketch is quickly approaching tricky shoals where it is important to know accurately the speed, direction, and depth of water. Without this critical information the voyage could come to a dramatic end. To confirm his suspicion that the knot meter is not working properly, Captain Granville rushes on deck and gives Rachel a stop watch. He asks her to start timing when the piece of bread he will drop, while standing on the bow, actually hits the water and to stop timing when she, standing 10 feet from the stern, passes the piece of bread. The ketch took 4.9 seconds to sail pass the bread. Using this old seaman's technique, Captain Granville computes that the ketch is actually going 6 knots rather than the 5 knots registered on the knot meter. Danger is imminent.

Based upon this situation, Ms. Lampert gave her students a series of questions. How did he figure the speed of the boat? How did he do it so rapidly? Continually being reminded that the real question had to do with whether the knot meter was working, students set about to construct a relationship between time, distance, and the speed. Individual students required different levels of explanation to understand how Captain Granville used the distance of 48 feet and the time of 4.9 seconds to compute the speed of the boat in knots. In the process of understanding what was done, students practiced computational procedures using fractions, decimals, and large whole numbers. The setting of the problem gave students a means of determining whether their computations "made sense." A question was raised, "If the boat travels 48 feet in 4.9 seconds, how far does it travel in one second?" The reasonableness of their computations to convert seconds to hours and feet to nautical miles could be compared to the knot meter reading of 5 knots. In this experience, questions were raised about placement of a decimal point in a product or about whether multiplication by 60 would be a more appropriate procedure than division.

The situation was extended when Ms. Lampert asked another question, "How could Captain Granville have figured the speed in knots *so quickly*?" This led to some suppositional reasoning as students tried to answer questions such as, What if the boat went by the bread in 3 sec? or 10 sec? or 8 sec? Students simulated these movements, made their computations, and concluded that no matter how many seconds were given, the same procedure could be used to find the speed. This experience in using a "formula" led students to generate charts of ordered pairs showing hypothetical times for the boat to pass the bread and the related speed. Some students wrote programs in LOGO on the Apple IIc to compute the speed when they typed in the time. This brought up the fact that a single constant could be used in the computation, $s = 28.4 \div t$. Next, graphing points on a grid was introduced as a *mathematical tool* to help the students see patterns. From plotting points, students observed that they seemed to fall on a nearly straight line. Extending this fitted line in either direction on a graph, students soon reached extrapolated points that did not make any sense: If the boat went by the bread in 12 sec, could its speed be 0? According to Lampert (1985), "They [students] could thus move from the specifics of *Mimi's* time and speed (i.e., having observed that the *more time* it takes for the boat to pass the bread, the *slower* the boat is going) to understanding the concept of an inverse proportion and its graph" (p. 161). The lesson was extended further by having students invent their own boats of reasonable lengths. Then a series of questions were considered: If the length of the boat changes, do the strategies we developed for changing from feet-per-second to nautical miles-per- hour still apply? Do the graphs of time and speed look similar? How are they like the time/speed graph for the *Mimi*? How are they different? How is the graph for a 12-foot-long sailfish different from the one for a 150-foot tall ship? (pp. 162-163).

The real-life situation provided the motivation and material for a very enriching mathematical experience in the hands of a creative teacher. Students employed proportional reasoning, computation, variables, formulas, tables, and graphs. The visual image of the *Mimi* sailing past a piece of bread helped students think about how speed varies with time and how one quantity varies with another. Lampert notes, however, that the real-life situation is not enough without teachers who have a strong understanding of mathematics and confidence in seeing the mathematics in situations. "Constructing serious mathematical explorations from real-life problems requires an appreciation of how mathematics can be used in a variety of situations to order, relate, and represent information in helpful ways. Organizing lessons that put the 'answer' in context and help students to look more carefully at creating strategies for *arriving at* an answer requires confidence in one's own as well as students' abilities to see mathematics as a set of ideas that make sense" (p. 165).

Early Classroom Implementation Studies

In the *Mimi*'s early years of implementation, a few studies were conducted on how teachers were using the multi-media package and on their inservice needs. The concept of using a multi-media curriculum package was new to teachers. The teachers who were willing to try or who were required to try the materials spoke very favorably about its use. Both the teachers and the students were enthusiastic about the experience.

One study conducted in 1985 (Storey & Julyan) asked 21 teachers from 14 schools in Massachusetts to respond to questionnaires about their use of the package. The schools were chosen from among 18 that had made the $1,000 investment in the *Mimi* package. The majority of the teachers taught students in Grade 5. Fifty-seven percent of the teachers in the study group were described as homeroom teachers and 43 per cent were science teachers. One fourth of the schools were in urban areas while the remaining were suburban schools. All of the teachers had used computers before, but most of them (71 per cent) had only used computers in the last three years. Nearly 90 per cent of the teachers rated themselves as experienced or moderately experienced with computers. Most of the teachers did not decide on their own to use the *Mimi* package. This decision was made by an administrator or other teachers. Only half of the teachers had attended a workshop outside of the classroom on the use of the materials. Nearly three quarters of the teachers received some form of assistance in using the materials from a media or computer specialist (40 per cent), a principal (33 per cent), or another teacher (33 per cent). Although the majority of teachers reported no difficulty in obtaining the necessary equipment for use of the package (VCR and computers), a few of the teachers reported difficulty in getting their class to computer locations (when there were no computers in the classroom) or bringing the computers to their classrooms. One school of 550 students only had 7 computers for the entire school. A teacher in another school could only use the *Mimi* two days a week because of the rotating schedule for the VCR. This teacher felt that such limited time was inadequate for students to get the full impact from the program and wanted to use a block of time each day for students to work on the materials. Another problem was that the software was designed to require one disc per computer to boot the computer. This time-consuming process forced one teacher to use a single computer for the whole class when any computer work was needed.

Fifth-grade teachers who worked with the program had enough knowledge of computers and instructional television that the use of these media was not an issue. It is not known whether the lack of such knowledge prohibited other teachers from using the package.

Teacher Practices

The package required teachers to approach their teaching in new ways. Teachers had to reflect on pedagogy and rethink their whole way of teaching. Because many teachers did not always know the answers to questions, they became more like coinvestigators with their students. The *Teacher Guide* urged teachers to collaborate. Teachers spent a significant amount of instructional time using the materials, as reported in the earlier studies. More than 80 percent of the teachers used the materials over a period of three months or longer. One teacher who tried to squeeze the use of the package into a two week period between holidays found that this time was insufficient for students to go into depth in the materials. This teacher spent 55 percent of the time on videos, 25 percent of the time with students using the printed materials, and only 10 percent of the time with students using computers. Another teacher spent more time on the software and the print materials and found that the guides were easy for students to follow. This teacher spent an equal amount of time on the video and computer components and the least amount of time on the printed material. Nearly 95 percent of the teachers rated the package as excellent or very good. Only one-fourth of the teachers reported that coordinating the various technologies and projects complicated their teaching. Teachers liked the mixed approach with hands-on materials. They found this to be different from the traditional textbook-based science program.

Student Activities

The use of the multi-media package resulted in students being more cooperative in working with each other. Teachers reported having no difficulty gaining the full participation of their students. Essentially all of the teachers felt that the multi-media package enhanced their students' learning; however, teachers did not employ formal means of assessment. One reason for this was that no tests were included in *The Voyage of the Mimi* materials. Most of the teachers, 62 percent, depended on class discussions for evaluating student learning. Less than half, 48 percent, used tests. Tests that were used were primarily vocabulary and did not measure students' knowledge of science and mathematics concepts. A fourth of the teachers used observations to evaluate student learning while only 5 percent had students do projects.

Some teachers felt that the experiences of their students in using the package were so positive that they did not want to impose formal evaluation. One teacher commented, "*Mimi* is a whole different category and I don't like to impinge on that by testing" (Storey & Julyan, 1985, p. 53). Those teachers who did test found that students learned what was being tested. Teachers valued the package not only for the content being presented but because of the students involvement in that content through the use of technology. When asked about their perceptions of the greatest strength of the package, 5 percent of the teachers reported the subject matter, 35 percent the technology, and 60 percent the combination of the subject matter and technology. "Teachers have reported that children have gained fluency with the concepts embedded in the games, although direct instruction about rate calculation, measurement techniques, and reading screens appears to be necessary" (Martin, 1987, p. 46).

Current Use of *The Voyage of the Mimi*

"There is a magic in the shows that touches our children and gets them interested again in learning. We use the programs nearly everyday to teach science/social studies. During class discussions of concepts, almost every child . . . asks questions or comments on the episodes," writes a special education teacher in an in-patient child psychiatry classroom at a large city hospital for seriously emotionally disturbed youngsters. On the shores of Long Island Sound, Gerri Faivre, a fifth-grade teacher at an independent school, uses *The Voyage of the Mimi* throughout the school year as central to her curriculum. Motivated by the series, her above-average students engage in independent studies of marine mammals, visit a whale discovery center, apply mathematical concepts when working on navigation charts, and become involved in other challenging activities. As a by-product of using *The Voyage of the Mimi* combined with a strong commitment to environmental concerns, the teachers, students, staff, and parents of the school have written a hardcover handbook containing a range of pieces related to the *Mimi* and the environment, including activities, history of nearby landmarks, prose, and sea food recipes. One student reflected on the series, "I really enjoyed my experience learning about 'The Voyage of the Mimi.' It was so intriguing. I wanted it never to end! They are great performers, everyone! It really is a fun way to learn about the ocean, math. science and much more combined into one. It's very realistic and exciting!"

Don Petersen, a seventh-grade science teacher in Dade County, Florida, captures the attention of his students in a dropout prevention program with The *Voyage* and uses ideas presented in the series as an entree into the science curriculum. Mathematical problems have been generated from situations presented in the video and computer simulations. He has developed an activity book that includes one classroom activity in each of four content areas (mathematics, science, language arts, and social studies) for each the 13 episodes. Joella Newberry, a Grade 6 teacher in Boulder, Colorado, has developed a list of topics for research projects her students do in association with *The Second Voyage of the Mimi.* Students work on their research projects for a week or longer and publish their reports using a computer. *The Voyage of the Mimi* and *The Second Voyage of the Mimi*, as these examples illustrate, are used in a variety of ways with a wide range of students.

Non-traditional teachers seem to have greater success in using the integrated *Mimi* package than more conventional teachers. Teachers confess that effort is required to use the different components of the package and to orchestrate meaningful experiences for students. Teachers have to be inventive and resourceful; they have to be comfortable in thinking globally; and they have to have some knowledge of how to use technology in instruction. Teachers committed to using the materials seem to be those who have special interest in the content. Mr. Petersen always wanted to be a oceanographer. Ms. Faivre is an avid sailor with a strong interest in the ocean. With effort, teachers are able to engage students in using the different components of video, computer, and print materials and to have them explore in depth scientific and mathematical ideas related to their own lives.

Teachers report using the materials in a variety of ways. Doug Lehnen, a microcomputer specialist in Pennsylvania, reported that teachers in his region use *The Voyage of the Mimi* package from one to nine weeks. Those using the material for the least amount of time only use the video series while those who spend more time on it will use a combination of the materials. Teachers in this region do not use the computer programming segment with LOGO because most of the students have already had experience with this language. Ms. Faivre builds her curriculum around the series. She will vary the use of the series based on the needs of the students for that year. The video expeditions are used to motivate in-depth studies of marine mammals and to provide lead-ins to field trips to such places as marine research centers. Mr. Petersen uses the series throughout the school year beginning in November. He has his students use the navigation software *Lost at Sea* and *Pirates Gold* and the computer model of an ecosystem (*Island Survivors*), but not the *Introduction to Computing*. In Colorado, Ms. Newberry uses *The Second Voyage* materials during two quarters of the school year. In her view, if teachers are to be successful with the materials they need to be inventive and resourceful; they need to be facilitators of learning rather than presenters of information. At least some training is required for many teachers to feel comfortable with the series. Mr. Petersen, who has conducted inservices on using the *Mimi*, felt that two days of training is enough to get teachers started.

Teachers have different purposes in using materials from the two *Voyages*. Some teachers show students the videos to motivate them and have them become interested in a related topic such as marine mammal research or electricity. Although students gain some knowledge of science and mathematics through the video and computer simulations, the materials are frequently used as motivation or as a catalyst for other activities from which students learn. Mr. Petersen, who teaches students in a dropout prevention program, described specific tasks students can do that are associated with viewing the video programs and working with the computer simulations and models. His students are able to triangulate the position of a boat within a few miles. They have worked real-world problems that require mathematical concepts. On one problem students had to plan as crew members on a ship how much food could be taken on a voyage. Students first determined the volume of the small rectangular storage space on the ship and then determined how many cans of soup, boxes of cereal, crates of produce, and other containers of food could fit into the available space. For homework students measured different containers of food and then computed what could fit into storage. Over the years his students, in association with using *The Voyage of the Mimi* series, have worked with scientific notation, volume, measurement, distance, rate, and time. Because he works with high-risk students, the grades he gives tend to reflect how much students are trying rather than their knowledge of mathematics and science.

On the basis of data obtained from the four people interviewed and the few studies that have been conducted on how teachers use *The Voyage of the Mimi*, it seems evident that students generally are not held accountable for learning mathematical ideas from the materials. Teachers do observe that students are able to triangulate the position of the ship; work with distance, time, and rate; and apply other mathematical ideas. However, their knowledge of mathematics based on use of the materials is generally not formally assessed. Mr. Petersen does give his classes a pre- and post-test, including questions on sailing terms and the scientific method, scientists' data collection techniques, the whaling industry, and endangered species. Ms. Newberry has her students do research projects based on topics associated with the series. Some of the topics approach the applications of mathematics -- for example, exploring different types of dating methods such as using Carbon 14, comparing the Mayan calendar with other calendars, and describing data gathering at an archeology site considering the frequency, depths, and types of artifacts found. In one region in Pennsylvania, teachers in the user group for the series will accumulate portfolios of students' work on writing and art activities associated with the series.

Mr. Lehmen, who works with teachers in his part of Pennsylvania, feels those who use *The Voyage of the Mimi* are so pleased with the interest the series has generated among the students that they do not want to discourage students by giving them tests on the material. He feels that the weakest feature of the package is the lack of assessment materials. The materials are used more as enrichment than as a central component of the curriculum. Some teachers viewed the series as a fun project and felt that students should not be weighted down with being assigned a grade for the knowledge they acquired from the experience. The feeling that formal assessment might detract from the experience is similar to what teachers reported in some of the earlier studies. Even though teachers do not formally assess their students' knowledge of the content covered in the *Mimi* materials, teachers feel that their students are learning and the time is well spent. Ms. Lavie did not formally grade students on what they learned from the multi-media package, but felt her students did well. She reported a range of activities on the part of her students that included using [illegible] and applying mathematical concepts while working on charts and with compasses.

One Teacher's Staff Development Effort in Using the *Voyage*

Over the period 1984-1986, the Mathematics, Science, and Technology Teacher Education Project (MASTTE), supported by funds from the National Science Foundation, trained teachers in 13 school districts around the country to use *The Voyage of the Mimi* (Martin, Hawkins, Gibbon, & McCarthy, 1988). A total of 18 teachers and 13 staff developers were provided 35 hours of training over a week during the summer of 1984 including 10 hours on content, 12 hours on philosophy/pedagogy, 6 hours on planning, and 4 hours on management. Teachers came from 37 schools located in 10 states: California, Massachusetts, Colorado, New Jersey, Georgia, New York, Hawaii, Ohio, Kentucky, and Washington. The majority of those receiving training had studied science methods (70 percent) and mathematics methods (65 percent). Many had science courses in college (72 percent of teachers and 83 percent of staff developers), but only a few had studied mathematics (16 percent of teachers and 30 percent of staff developers). A large proportion of the participants, 84 percent, had had some computer experience.

According to a follow-up study conducted to determine how the *Mimi* package was used and how the different hardware and materials were integrated, most teachers were using the materials as a science program. By the end of the second year of the project, 12 districts were still participating. Only one of these indicated that the package was being used in mathematics. This was in a district where the a cross-curricular connections were emphasized among science, bilingual education, special education, social studies, language arts, and mathematics. Eight of the sites used the materials primarily as a science curriculum or integrated it with particular topics in the science curriculum. Four of the sites, including the one mentioned above, used the materials as the basis for integrated curricula, generally with science and language arts. One site focused on the software and used the different modules at different grade levels (*Introduction to Computing* in Grade 4, *Maps and Navigation* in Grade 5, *Ecosystems* and *Whales and Their Environment* with the *Bank Street Laboratory (MBL)* in Grade 6.

Teachers had difficulty in operating the "novel" configuration of technology and had to receive assistance from the MASTTE staff. Teachers left the training with a different perception of the program based on their backgrounds, their level of awareness of the purpose of the multi-media package, and local curriculum demands. At the outset, teachers overwhelmingly tended to direct the instruction to the extent of "holding discussions that turned out to be fact-laden lectures" (Martin, et al, 1988, pp. 181-182). This approach contradicted the intent of the developers who intended for the materials to encourage inquiry in science and mathematics. Receiving on site help in impl'menting the series and in the use of technology [illegible] the restricted application of the materials.

Experienced science teachers, to a greater extent than the less-experienced teachers, developed a range of units based on the *Mimi* that were creative and more apt to include computer-based activities. The video did promote students' curiosity in science and prompted them to ask questions. The modules varied in their appeal. The *Maps and Navigation* and *Ecosystems* components were the most widely used because they related well to topics in the video series and corresponded to topics in the existing curriculum. "*Navigation* represented an unusual but exciting mathematics theme, one that teachers enjoyed learning and demonstrating" (Martin, Hawkins, Gibbon, & McCarthy, 1988, p. 183). The *MBL* in *Whales and their Environment*, and the *Introduction to Computing* were more difficult to integrate into the instructional program. The complex concepts, the different instruments, and tricky hardware created major problems for teachers. The *Computing* module was superfluous for many teachers whose classes were already using LOGO. Conclusions drawn from this study of a teacher training program indicated that most teachers needed training to tackle the materials and to take advantage of the full range of opportunities the technology affords.

ISSUES RELATED TO THE MULTI-MEDIA INTERDISCIPLINARY INSTRUCTION AND IMPACT OF THE *MIMI* MATERIALS

In preparing this case study information has been sought about issues related to current mathematics education reform efforts. *The Voyage of the Mimi* Project has generated materials that have helped teachers use technology in their classrooms, provided students with experiences requiring the use of knowledge from more than one content area, and served as a catalyst for other learning activities. The materials that have been produced do not comprise a self-contained curriculum that encompasses all the procedures and student activities needed to attain specific outcomes, but are a rich set of organic instructional situations that can give middle grade students cognitive experiences that use a variety of modes of presentation. Teachers who understand the riches of the materials have been able to use them to engage their students in inquiry and investigations, to motivate them, and to build instructional experiences. The materials are diverse enough that teachers can use only the video programs as a dramatic series, or use the range of components that encourage students do science, use technology, and apply mathematics. As a contribution to education reform, the project has strived to meet many of the criteria for change being recommended for mathematics curriculum reform. As a case study, then, *The Voyage of the Mimi* provides an entree for studying the substance of the current reform efforts.

The Issue of Mathematics in Context

The Voyage of the Mimi's scientific explorations are interspersed with mathematical situations at specific points as the adventure unfolds. At these points, the mathematics is a response to a need to apply mathematical concepts, procedures, and thinking to reach conclusions and solutions. Angles and coordinates have to be employed in the context of navigation. Proportional reasoning is applied to compute the speed of a ship. Spatial measurements are calculated in determining the capacity of storage areas on the vessel. In *The Second Voyage*, an archaeological investigation of the trading routes of the Maya, students work with the base 20 number system to better understand the Mayan calendar. The materials provide the potential for students and teachers to work with mathematics in real-world contexts, but depend heavily on the creativity and initiative of the teacher in taking full advantage of the contextual richness to prompt applications of mathematics.

The stories in the two voyages are compelling for students and teachers. A considerable outlay of time and resources was employed to produce high quality video dramas. The story motivates, generates, and situates the learning of content. According to the project's executive director, the two *Mimi* series confirm what others have long known: the importance of story in people's lives. The story can strike a deep cord in people. Good teachers understand the power of stories and structure lessons with a beginning, middle, and end, threaded by suspense. Whereas many approach learning analytically, the experience with the two story-based series suggest that a narrative approach can be valuable in learning mathematics and science. Some teachers have found that just replaying a 30-second segment is enough to revive interest in an extended task such as computing the speed of a ship.

Even with the contextual richness the package brings to the classroom, hard evidence of students' learning mathematics as it is applied in meaningful situations through using the *Mimi* materials could not be documented. Objectives that communicate what mathematics students can learn through working with the materials, software, and context are absent from the materials. Teachers and students are to infer from the activities what is to be learned. The stated learning objectives in the *Overview Guide* are direct and descriptive, but do not specify the knowledge students should attain--for example, learning about chart coordinates, identifying locations on a map by their coordinates, putting chart coordinates on a map, and applying knowledge of chart coordinates to the drawing of a contour map of the ocean floor. As noted earlier, the strong positive experience students have with the materials is so overwhelming that some teachers report they are reluctant to detract from this experience by requiring students to demonstrate what they have learned.

The Issue of Integrating Mathematics with Other Content Areas

Barriers abound that serv d to inhibit the true integration of mathematics with science and other content areas in the series. The story line based on the study of whales, chosen because of the topic's strong attraction to students in the middle grades, engenders more readily the learning of science ideas than of mathematics. The partitioning of the school day into subject area periods and classes being taught by subject matter specialists prevents students from working with an integrated curriculum. The developers also found the task of creating interdisciplinary materials to be very difficult. This resulted in designing the first package with a much stronger emphasis on science and developing the second package with more apparent mathematical topics as a compensation. In both packages, mathematics and science topics are prominent and interesting experiences are provided for students to use mathematics within a science context. At least one Grade 5 teacher uses the package for building her curriculum for all content areas. In the hands of a creative teacher, the materials have the potential of truly functioning as an interdisciplinary curriculum. What seems more prevalent, however, is for the package to be used in conjunction with a science program. No claim is made that the materials represent, nor do they constitute, a complete science or mathematics curriculum. For teachers to fully integrate them into an existing program, some work is needed to form a link between what is presented in the video and computer software with the standard curriculum. This, again, requires initiative and effort by the teacher to make all of the pieces fit together.

The Issue of Technology in Instruction

The developers deliberately created the computer software and video to be used by technology prevalent at the time the project began. No attempt was made to upgrade the materials to keep pace with the changing capabilities of new hardware on the market, except to develop software for the second package to perform on the *Apple IIe* with its increased memory. As a consequence, teachers did not encounter any real problems in finding the necessary equipment to use the materials as designed. Information is not available on teachers who did not use the materials because of lack of access to the needed equipment. During the 10 years since the initiation of the project--a period of many technological advances--teachers did report some inconvenience in having to use a different disc to boot each computer. Upgrading the materials for more advanced technology -- *Macintosh* and videodisc -- has been done for some of the components. This conversion was undertaken by the publishing company because of market pressures. The process is costly and requires some coordination with the Bank Street College of Education, which still controls the copyright.

Teachers varied considerably in how they used the materials and in what components they used. Some used only the video drama. Some only used the video expeditions. Teachers with three to five computers in a classroom had no difficulty in providing their students adequate access to the computer software, usually by developing a rotation scheme so that each student would have some time on the computer, either individually or in a small group, once a week. Even teachers with one computer were able to make use of the software. As previously mentioned, some teachers had difficulty in using the *Bank Street Laboratory* because of problems in connecting the apparatus into the computer and dealing with equipment breakdown. Besides these two modules, however, teachers felt very comfortable in selecting and choosing what combination of materials from the package they would use. There seems to be no data that relates the students' use of the different technology components specifically to what they learned.

The Issue of Influence of One Project on Others

Derivatives of the two *Voyages* series are difficult to document. The mix of drama with documentary in an educational video series was not prevalent in the early 1980s and was considered by the executive director as a major contribution of the *Mimi* Project. The software produced and the interaction between the different media have been imitated more than they have served as an inspiration for the development of other similar systems. Those working with CDROM and videodiscs have noted with interest the multi-media package used in the *Mimi* Project. For example, one company, developing Digital Video Interactive (DVI) discs, was given a demonstration of software used in the *Mimi* series. It is possible, but not known for certain, that this demonstration then influenced the development of multi-media educational materials for this MS-DOS environment. One product that is now available as part of *The Second Voyage of the Mimi* series is *Palenque*. This uses DVI technology to offer actual video footage on the computer screen to provide students an opportunity to investigate the culture, history, archaeology, and geography at a 7th Century Mayan site. Students, using a joy stick, can climb about the temple and change the perspective or fly, via aerial video, over the surrounding rain forest.

Developers of multi-media curriculum projects that began development in the mid-1980s, after *The Voyage of the Mimi* had been published, report being aware of the *Mimi* materials but not really influenced by them. The *Adventures of Jasper Woodbury* is based on a data-embedded video on videodisc. A story line presents a problem, but the solution is left for the students to provide. Students are able to review data from the video by quickly accessing and viewing 1- or 2-minute segments. These materials have been developed by a group at Vanderbilt University to give middle grades students mathematical problem-solving experiences grounded in meaningful contexts. The developers of this project, funded by the National Science Foundation, were aware of the *Mimi* materials but did not really refer to them in developing their materials.

Some of the developers of the National Geographic Society's *Kids Network*, produced by the Technical Education Research Center (and one of the case studies on innovations in science education in this series of studies), were active on *The Voyage of the Mimi* Project. Although parallels in structure could be drawn between the two sets of materials, a developer of the *Kids Network* who had worked on the *Mimi* Project could not find any apparent influence of the *Mimi* had on the later project. She did note that in creating a multi-media experience, the learning environment is structured to provide students with a shared experience. In the *Mimi* series, the video series is shared with the drama of studying whales and the adventures of the characters. By contrast, the shared experience for students working with *Kids Network* is data. These data are not only shared with students in the same classroom, but also with students on the network from other schools, states, and countries. One objective of both the *Mimi* and the *Network* was to have students work with their hands and become physically engaged in doing science and mathematics. The *Mimi* uses computer simulation whereas the *Network* does not. However, both series sought to have students view computers as a tool for scientists and learn how to use computers.

Both *The Voyage of the Mimi* and *Kids Network* series present challenges to teachers. The *Network* is more structured than the *Mimi* and has a clear instructional map with many detours for adventures. The complexity, however, is not as much associated with the use of different media or with teacher management issues as it is with the effort to have students construct their understanding of science and mathematics through these experiences. As with the *Mimi*, assessment was not built into the first set of *Kids Network* materials because of the feeling that assessment materials could only be developed after a stable curriculum had evolved. Because of pressure from teachers asking for the means to grade students, the next evolution of the *Network* will be developed with some built-in assessment materials.

There are strong parallels between these two projects that derive from their attempts to use different types of technology, their purpose of providing real experiences, and their integration of content. But even with these strong parallels, the lessons learned during development of the *Mimi* Project seem to be confined to that project rather than transferable to later iterations of multi-media materials development.

REFLECTIONS

The Voyage of the Mimi materials provide a rich environment for middle grade students to experience some new mathematics concepts. Teachers who are creative and innovative have used the different components to guide their students in expanding their applications of mathematics. But the mathematical experiences are viewed more as enrichment than as central to objectives for which students are held accountable. The mathematics that is done is presented in a broader context rather than as isolated skills. Doing mathematics in the context of a scientific expedition made the material appear to be interdisciplinary, although the series seems, as noted previously, to be used most frequently by teachers as a science program.

Technology is employed in the series in many different ways. The video series--that is, the episodes and expeditions -- is central and the most widely implemented component. The computer simulations in the *Maps and Navigation* module and the computer model in the *Ecosystems* module are the most popular software. The *Mimi* series is somewhat unusual because of the range in computer applications -- simulations, modeling, and programming -- that are provided. The decision to develop materials for the most widely used and up-to-date technology hardware at the beginning of the project has enabled teachers to use the materials at least into the 1990s. The conversion of materials to more advanced technology is being done, but this decision is driven more by the market than by pedagogical objectives.

Finally, the transfer of experience and knowledge from one multi-media project to another does not seem to be prevalent among the few projects reviewed. Even though developers of projects are aware of others, such as *The Voyage of the Mimi*, they do not seem to have paid much attention to what was done in other projects or find that there was enough in common among the projects to spend time to learn from another project. Multi-media and multi-disciplinary projects may share commonalities and similar issues in providing students a shared experience, in seeking to have students construct their understanding of the different disciplines, and in encouraging students to apply technologies used by those in other disciplines. But, even with these commonalities, projects often differ enough in their approaches that they are unable to benefit greatly from the achievements of another project. What appears to be more transportable between projects is the development of particular techniques or equipment.

QUESTIONS FOR PHASE II

This case study of *The Voyage of the Mimi* Project depended heavily on existing information, telephone interviews of those who worked on the project, and telephone interviews of four educators who are currently active in using the materials. The information collected helped to obtain answers to some of the questions raised at the beginning of the study. A more thorough study can provide more precise answers and respond to a number of questions generated from this preliminary case study.

1. How have *The Voyage of the Mimi* materials been used by teachers to further the ideals of the current mathematics reform efforts in making connections between mathematics and other subject matters, offering different forms of representation, and providing further opportunities for learning mathematics?

2. Because teacher initiative appears to be critical in the full use of materials from the *Mimi* series, what teacher characteristics and professional development experiences empower teachers to mine the richness from the multi-media materials?

3. How have teachers who use the *Mimi* series adapted to the increased pressure of accountability and what evidence has been generated that students learn mathematics and science from using the materials?

4. Are the equipment requirements, structure of materials, and interdisciplinary nature of the series preventing teachers from using *The Voyage of the Mimi* more extensively? If so, why?

5. What institutional support do teachers need in order to successfully use and to stimulate continued interest in using the series?

6. How have the adaptations of the materials to newer forms of technology increased or modified teachers' use of the two *Mimi* series and what students learn in the process of using them?

SOURCES OF INFORMATION

WINGS for learning was very cooperative in making a complete package of *The Voyage of the Mimi* materials available for a content analysis. The reports on studies conducted on the implementation of the materials and on the professional development needs of teachers that were consulted are listed in the references. The following people were either personally interviewed or interviewed by telephone: Samuel Y. Gibbon, Jr., formally the executive director of *The Voyage of the Mimi* Project and now with the Alfred P. Sloan Foundation; Lorin A. Driggs, formally the editor and still at Bank Street College; Donna Kemper, *WINGS for learning*; Doug Lehnen, microcomputer specialist for a region in the state of Pennsylvania; Joella Newberry, a Grade 6 teacher at Bear Creek Elementary School in Boulder, Colorado; Gerri Faivre, a Grade 5 teacher at East Woods School, Oyster Bay, New York; Don Petersen, a Grade 7 science teacher in Dade County, Florida; Candance Julyan, consultant for *The Voyage of the Mimi* Project, now developer of *Kids Network* for the Technical Education Research Center, Cambridge, Massachusetts; and John D. Bransford, director of the *Adventures of Jasper Woodbury* Project, Vanderbilt University, Nashville, Tennessee.

REFERENCES

Bank Street College Project in Science and Mathematics. (1985). *The Voyage of the Mimi: Overview Guide.* Scotts Valley, California: *Wings for learning*, Inc.

Fisch, S. M., Hall, E. R., & Esty, E. T. (1991). Designing assessment of mathematical problem solving for elementary-school children. Paper presented at the International Commission on Mathematics Instruction Conference on Assessment in Mathematics Education and its Effects, Calonge, Spain.

International Business Machines. (1988). *Mathematics Exploration Toolkit.* Developed for IBM by WICAT Systems, Inc.

Key Curriculum Press. (1990). *Geometric sketchpad.* Software produced by Key Curriculum Press, Berkeley, California.

Lampert, M. (1985). Mathematics learning in context: *The Voyage of the Mimi. The Journal of Mathematical Behavior 4*, pp. 157-167.

Martin, Laura M. W. (1987). Teachers' adoption of multi-media technologies for science and mathematics instruction. In Roy D. Pea and Karen Sheingold (Eds.), *Mirrors of minds: Patterns of experience in educational computing.* Papers from the Center for Children and Technology, Bank Street College. Norwood, NJ: Ablex Publishing Corporation, pp. 35-56.

Martin, L. M. W., Hawkins, J., Gibbon, S. Y., & McCarthy, R. (1988). Integrating information technologies into instruction: *The Voyage of the Mimi.* In J. D. Ellis (Ed.), *1988 AETS yearbook: Information technology and science education.* Columbus, Ohio: ERIC Clearinghouse for Science, Mathematics and Environmental Education, The Ohio State University. pp. 173-186.

National Center for Education Statistics. (1991). *The state of mathematics achievement, NAEP's 1990 assessment of the nation and the trial assessment of the states.* Washington, DC: United States Department of Education.

National Science Board. (1989). *Science & engineering indicators--1989.* Washington, DC: U.S. Government Printing Office, p. 164. (NSB 89-1)

Storey, K. S. & Julyan, C. L. (1985). *The integrated design and use of computers and television in education.* Technical Research Report. Computers and Television Project, New Technologies Group, Educational Technology Center. Cambridge, MA: Harvard Graduate School of Education, July. ERIC ED295 617.

Weiss, I. R. (1987). *Report of the 1985-86 National Survey of Science and Mathematics Education.* Research Triangle Park, North Carolina:Research Triangle Institute.

WINGS for learning. (1991). *The Mimi experience.* Scotts Valley, California: *Wings for learning*, Inc., *3*, No. 2, (Winter).

Yerushalmy, M., & Schwartz, J. (1985). *Geometric Supposer.* Software developed by Educational Development Center, Inc., Pleasantville, NY: Sunburst Communications.

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